MAGIS-100 at Fermilab:

100m atom interferometric quantum sensor

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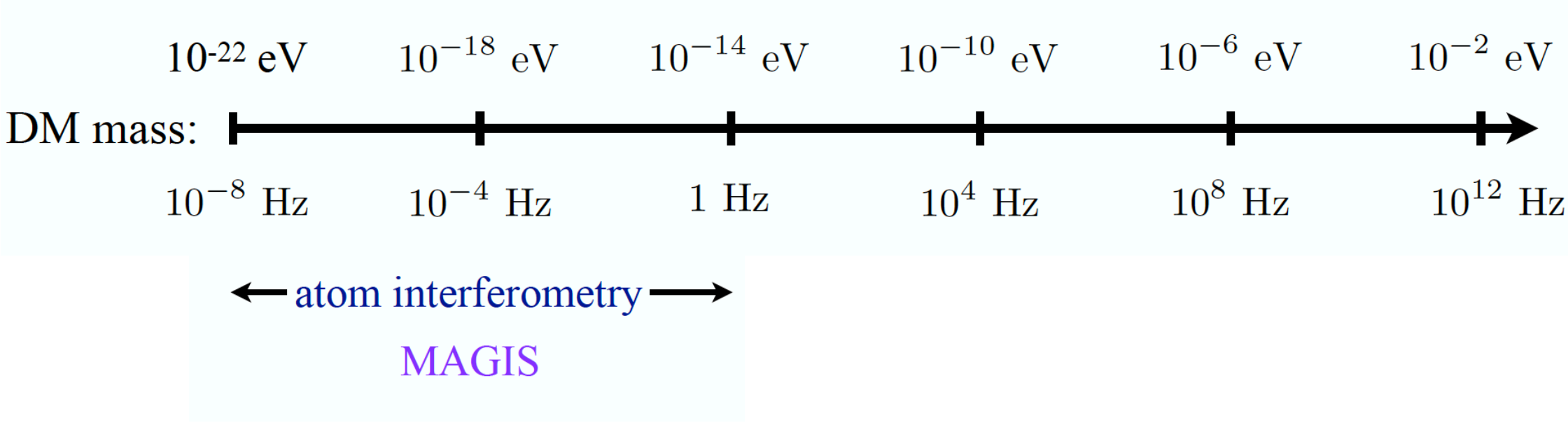
On behalf of the collaboration

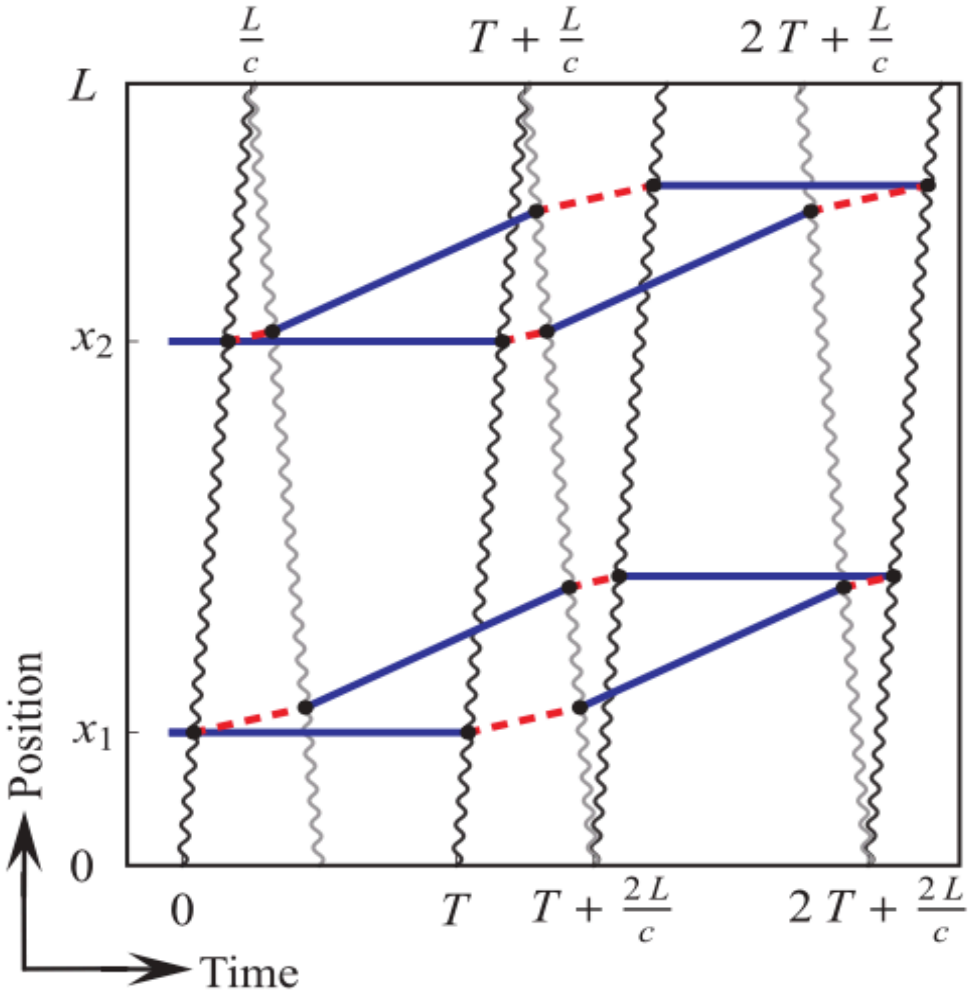
HEP Forum: 10/11/2020

Fermilab · University of Oxford · Stanford · University of Cambridge · University of Liverpool · Northwestern University · Johns Hopkins University · Northern Illinois University

Science Motivation



Light-pulse Atom Interferometry



- Atoms as de Broglie waves in superposition of states
- Large wavepacket separation to increase sensitivity

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

Ultralight dark matter signal

Gravitational wave signal

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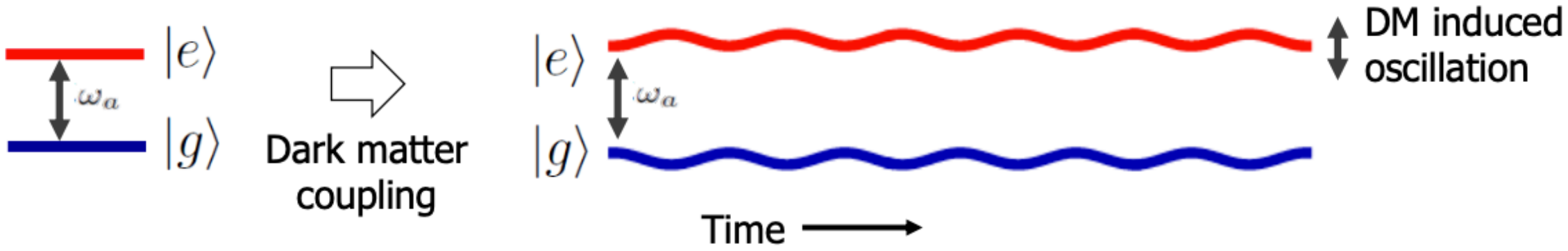
Dark Matter Detection with MAGIS

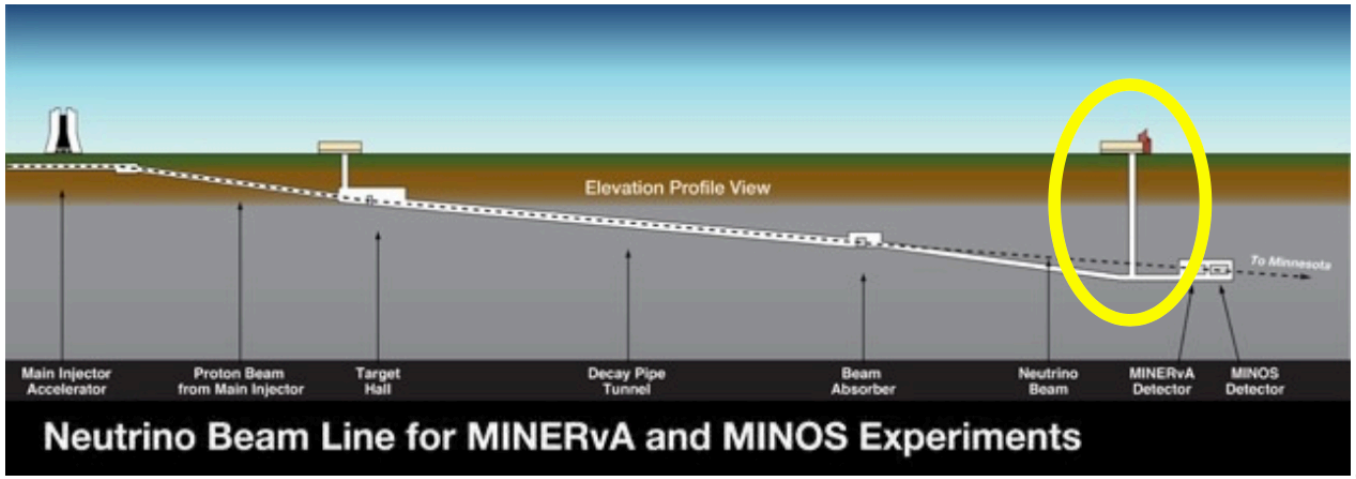
- Affects fundamental constants (m_e and α), altering atomic energy level separation

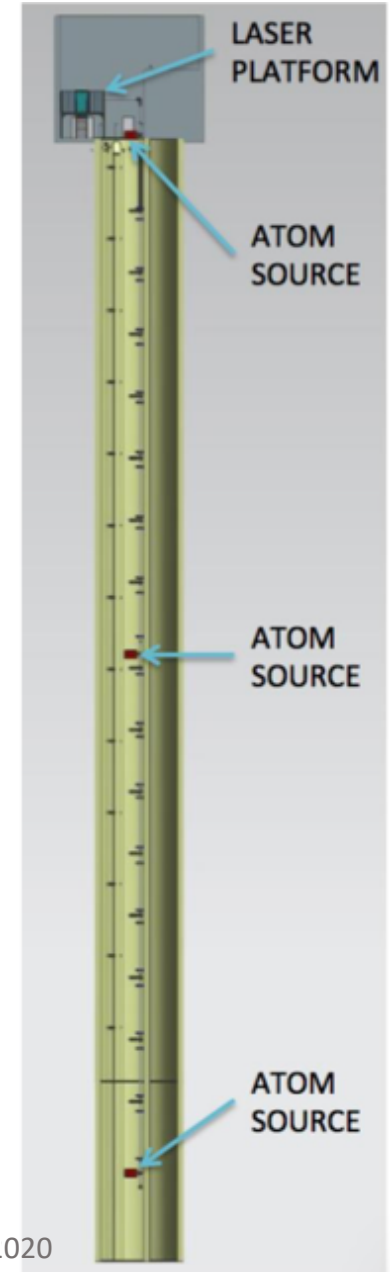


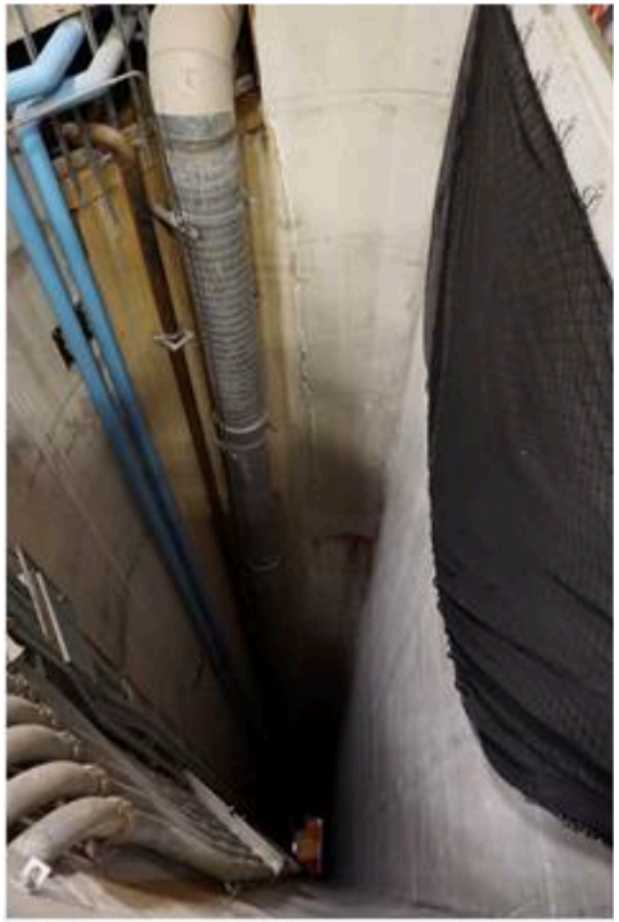
- Same configuration used for gravitational wave measurements
  - Compare light travel time across the baseline

MAGIS-100 @ Fermilab

- 100m baseline – MINOS access shaft
- 3 interferometers & 3 Sr atom sources
  - Differential measurements, GGN
- Sensitivity proportional to baseline L
  - 2L/c ~ gravitational wave signal
- UK networking with AION







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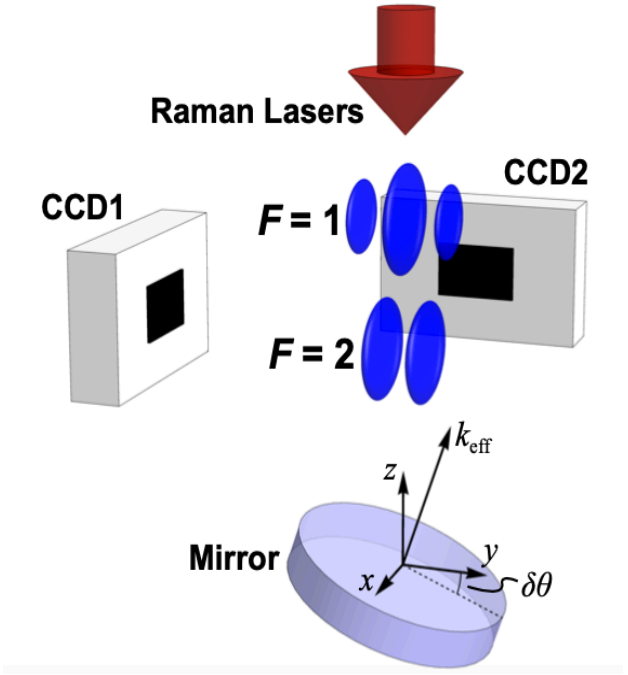
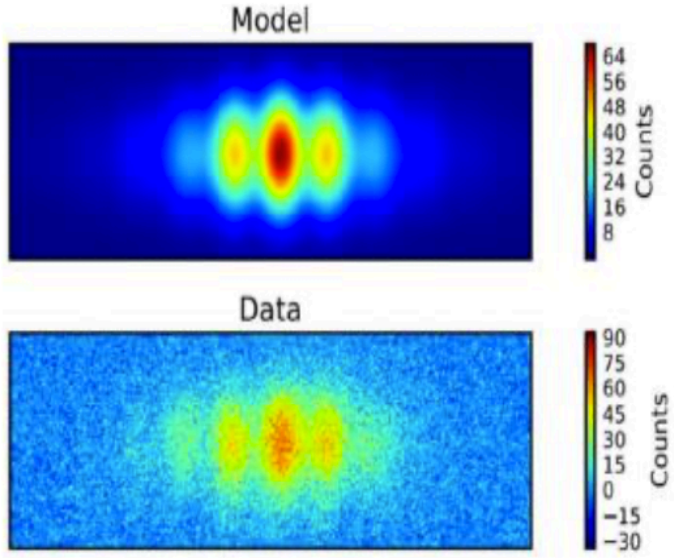
UK contribution: Detection System

(Cambridge, Liverpool and Oxford)

- Low noise EMCCD cameras
- High precision in-vacuum optics & mechanical support structure
  - Enables phase shear measurements
- DAQ, readout, data pipeline, computing, etc.
- Simulations
  - Modelling associated signal and noise, systematics…





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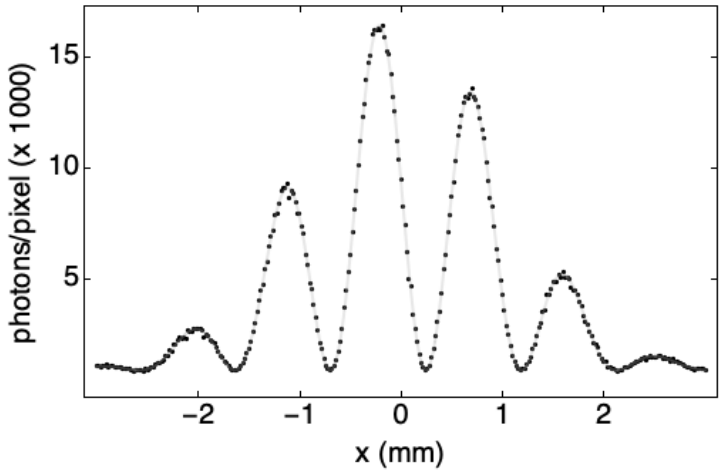
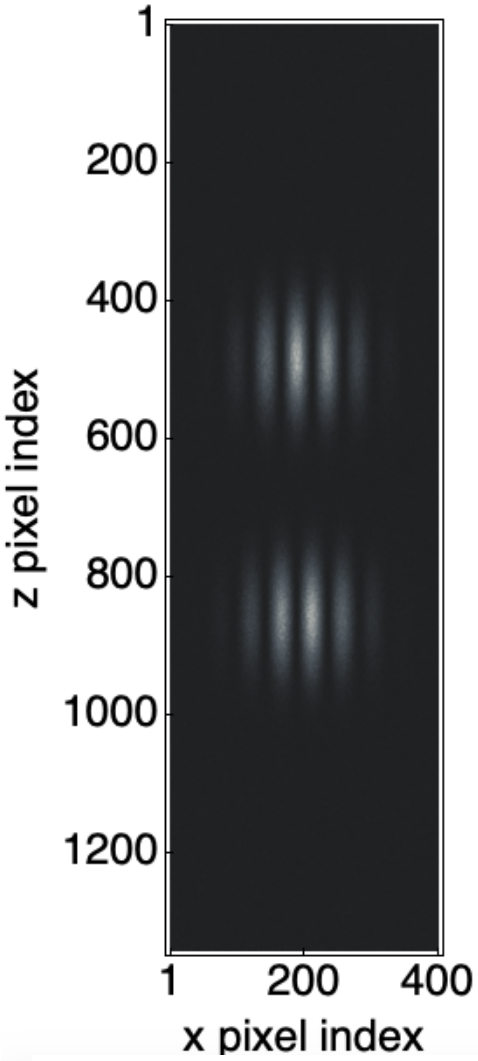
UK contribution: Simulations

(Cambridge, Liverpool and Oxford)

- Take wavefunction at end of interferometer
- Modelling systematics
  - Camera parameters, optics, noise, diffusion, cooling, etc.
- Comparing precisions of fitting methods for phase
- Developing prototype analysis tools





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Summary: MAGIS-100

- Atom interferometers separated by ~100m baseline at Fermilab
  - Prototype for 1km at SURF
- Testing QM on large scales, searching for ultralight dark matter and test bed for gravitational wave detection
- Part of Fermilab Quantum Institute and DOE's QuantISED programme (OHEP)
- UK particle physics groups (Cambridge, Liverpool, Oxford) contributing detection system & simulation work
  - As part of the AION programme

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Questions?

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Backup Slides

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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

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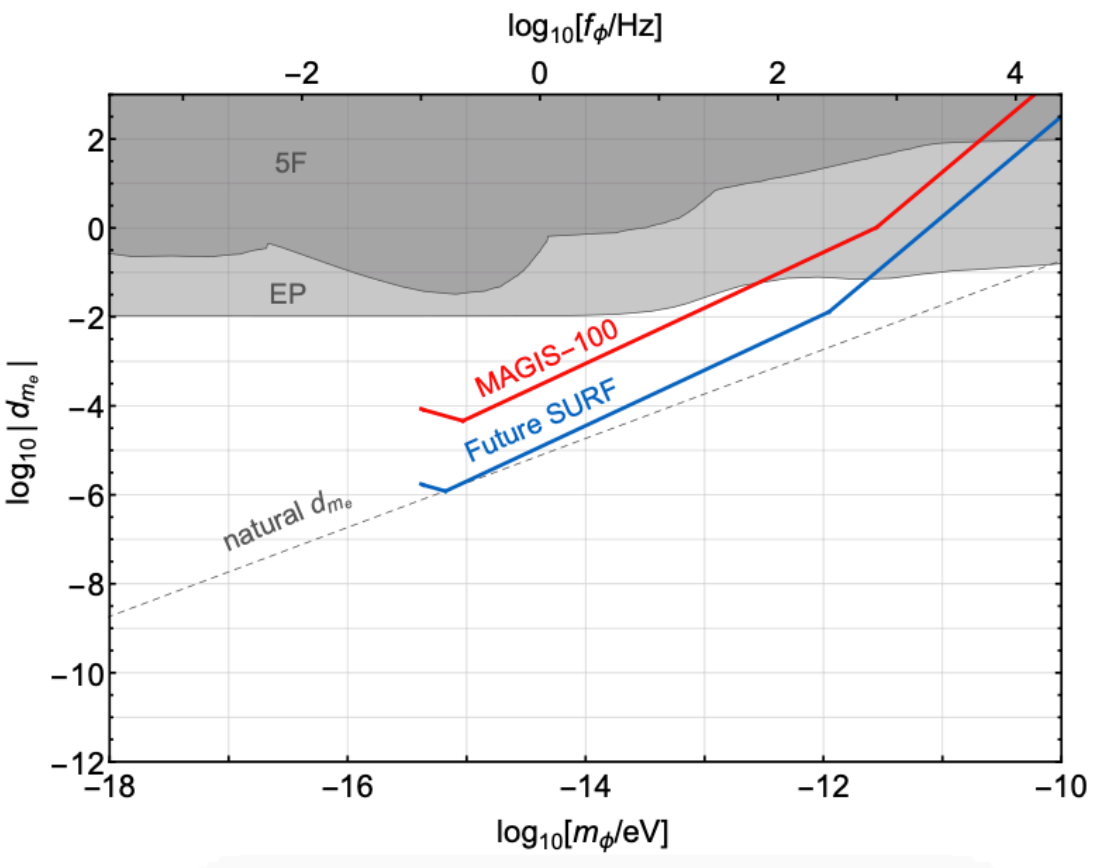
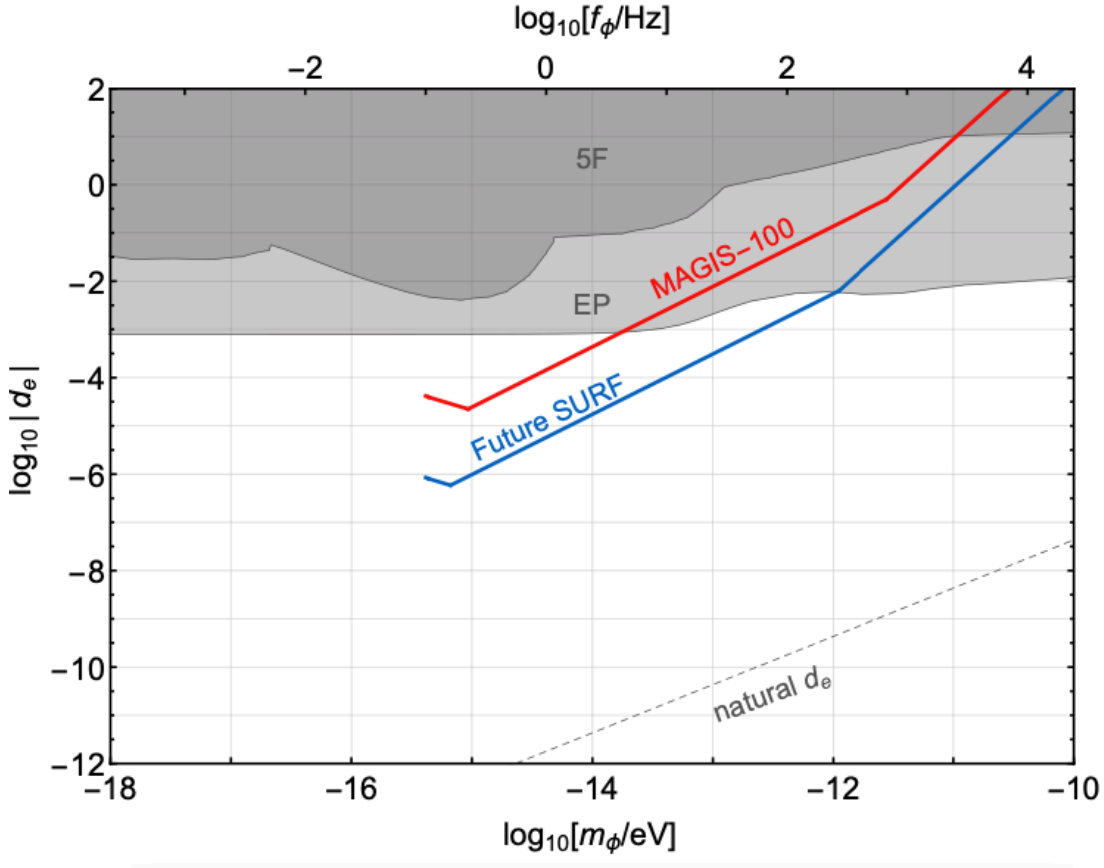
Alternative Dark Matter Detection Methods

- Effects on fundamental constants – scalar
- Causes accelerations to test masses – vector
  - Using isotopes of strontium
  - Comparing accelerations
- Precessions of nuclear spins – pseudo scalar
  - Placing atoms in different spin states

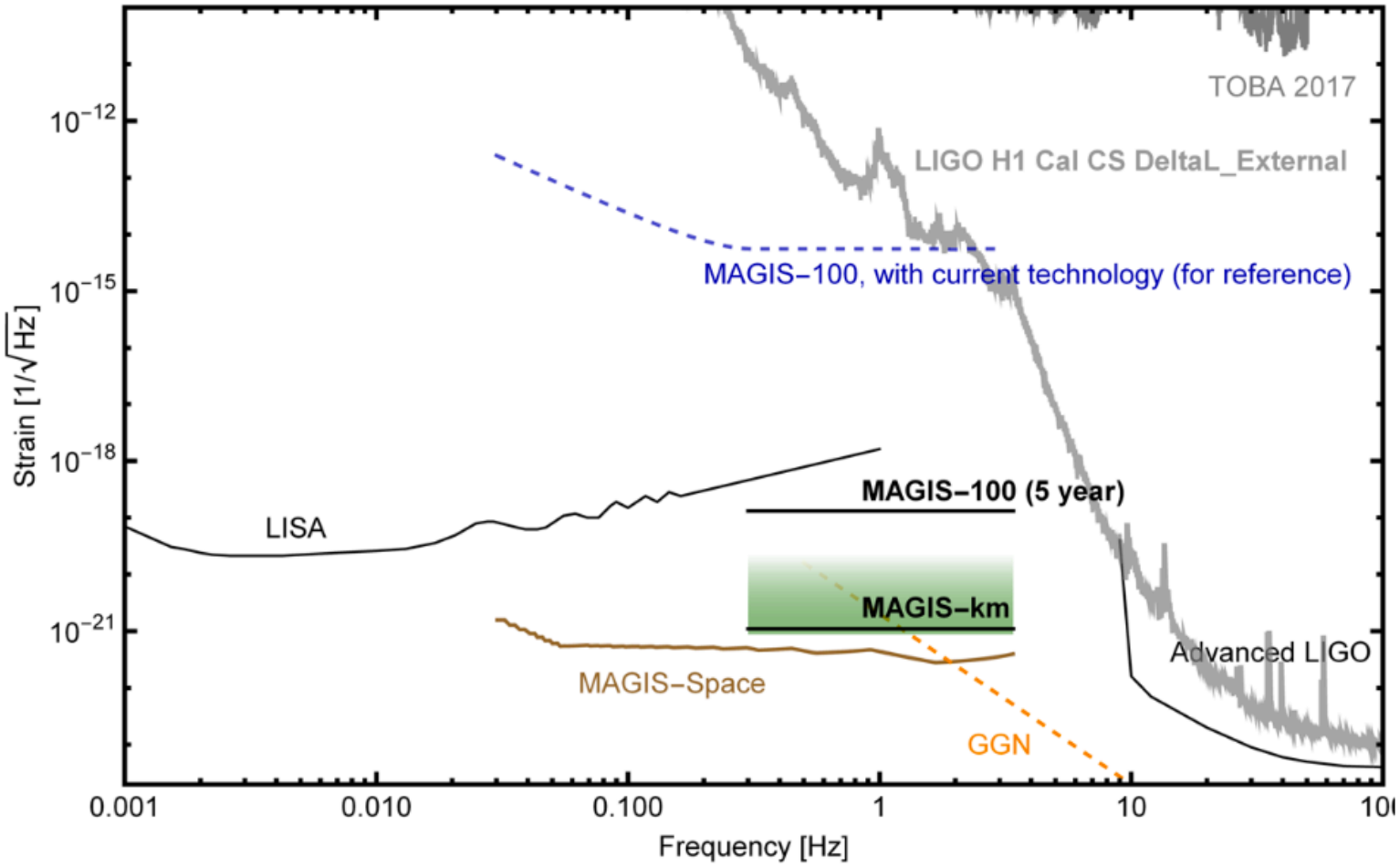
Sensitivity via Coupling to m_e and α





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

Sensitivity to Gravitational Waves



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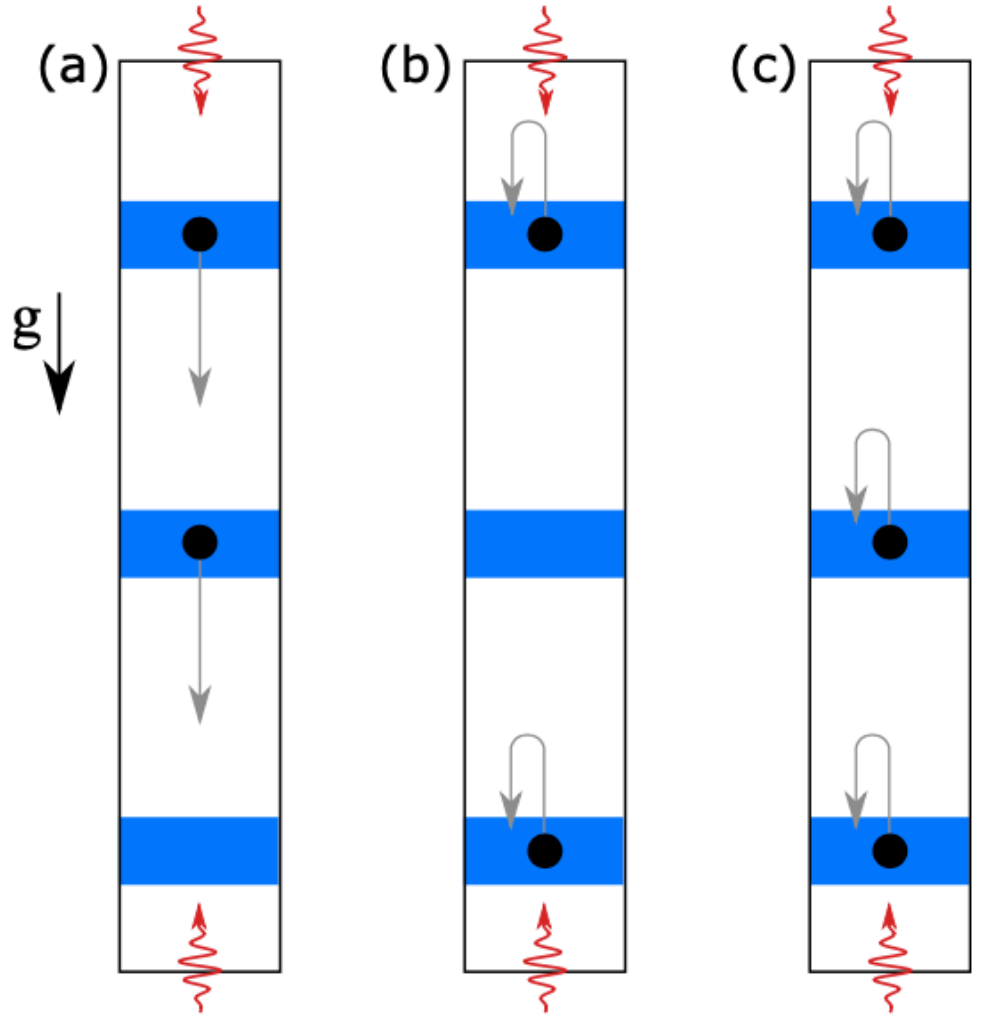
Baseline Configurations



a. Max drop time

b. Max baseline

c. GGN characterization