

MAGIS and Long-Baseline Atomic Sensors

LOI: *"Snowmass2021 Letter of Interest: Long-baseline Atomic Sensors for Fundamental Physics"*

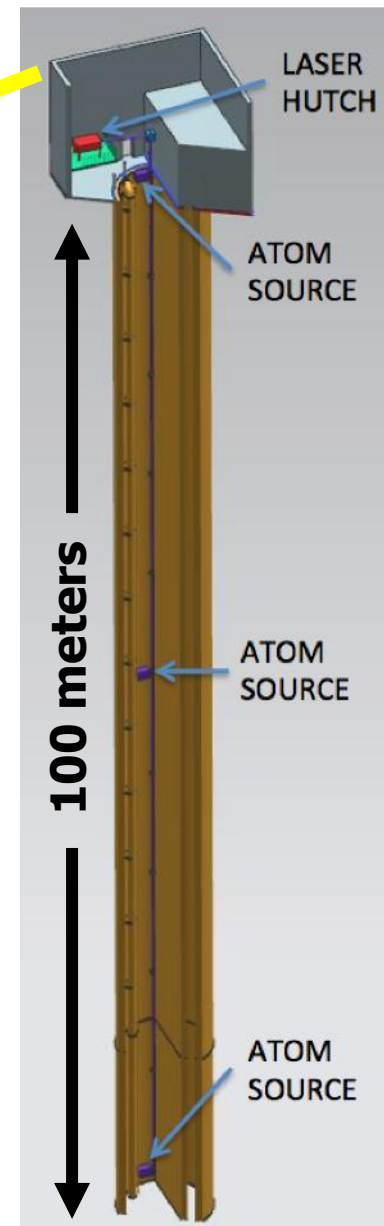
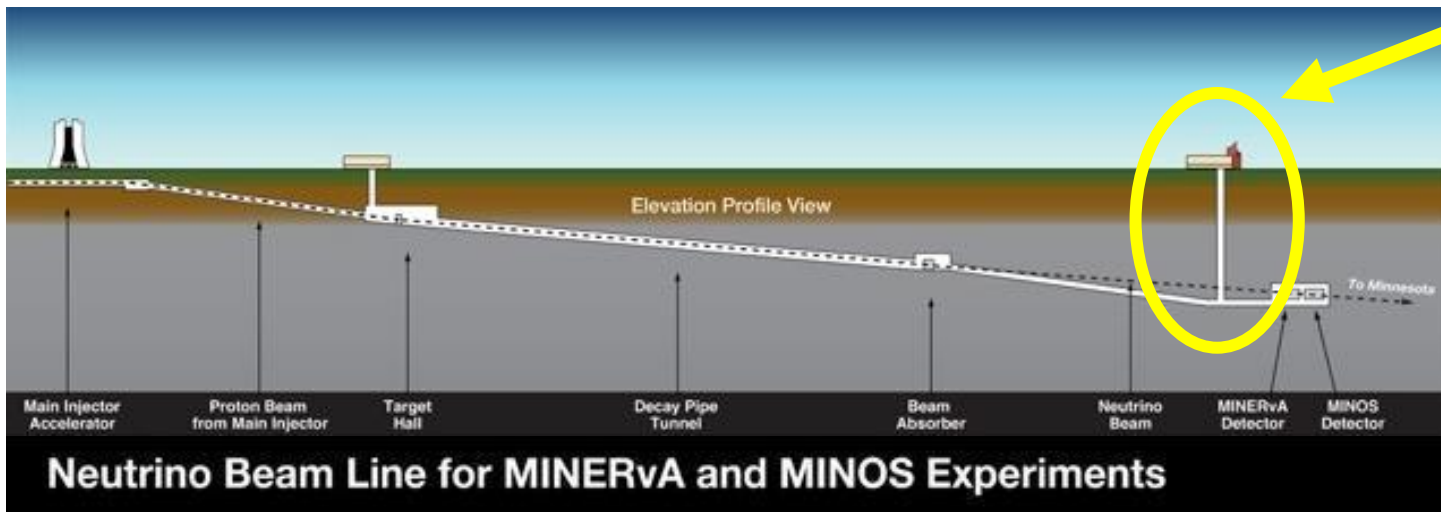
LOI authors: Jason M. Hogan, Ariel Schwartzman, Peter Graham, Surjeet Rajendran, Tim Kovachy, Swapan Chattopadhyay, Rob Plunkett, Steve Geer, Jonathon Coleman, Valerie Gibson, John March-Russell, and the MAGIS collaboration

SNOWMASS Wave Dark Matter Community Talks

Jason Hogan
Stanford University
October 6, 2021

Current experimental work: MAGIS-100

Matter wave Atomic Gradiometer Interferometric Sensor



- **MAGIS-100** is a 100-meter-scale atomic sensor experiment located at Fermilab
- Currently under construction; begin commissioning in late 2022
- ~\$15M scope (Gordon and Betty Moore Foundation + DOE QuantiSED funding)
- International collaboration of 10 institutions, >50 people



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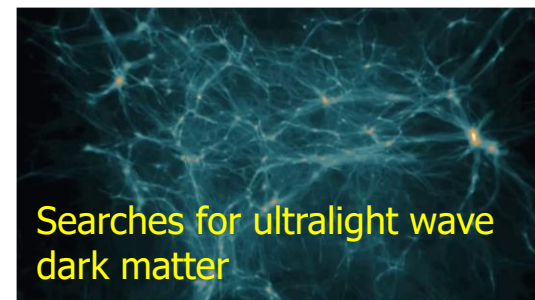


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Long baseline atom interferometry science

Ultralight wave-like dark matter probe

- Scalar- and vector-coupled DM candidates
- Mass $< 10^{-14}$ eV (Compton frequency in \sim Hz range)
- Search at sensitivities orders of magnitude beyond current limits

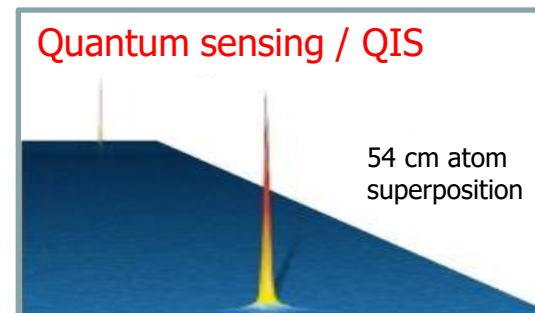


Fifth force searches

- EP-violating new forces (time-varying and static)
- Sourced by Earth or local test mass

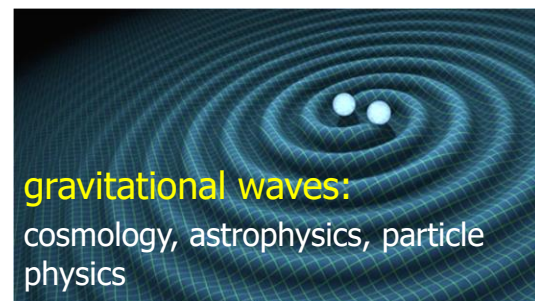
Tests of quantum mechanics at macroscopic scales

- Meter-scale wavepacket separation, duration of seconds
- Decoherence, spontaneous localization, non-linear QM



Mid-band gravitational wave detection

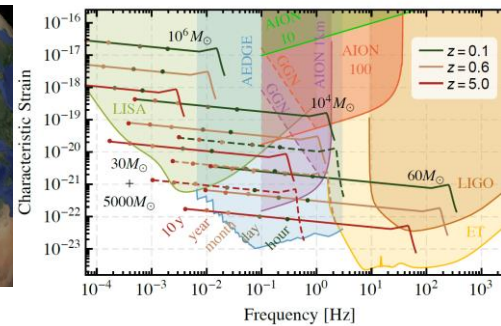
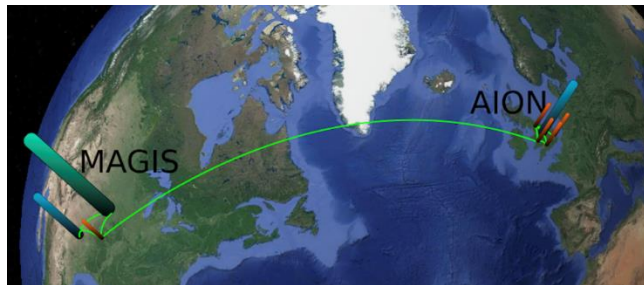
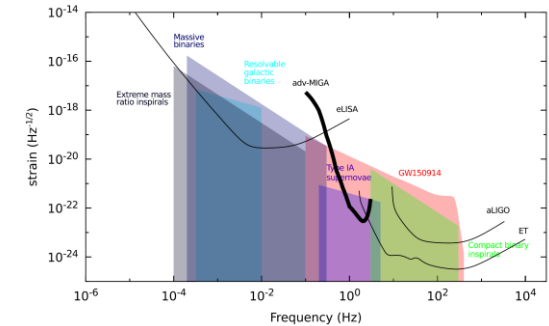
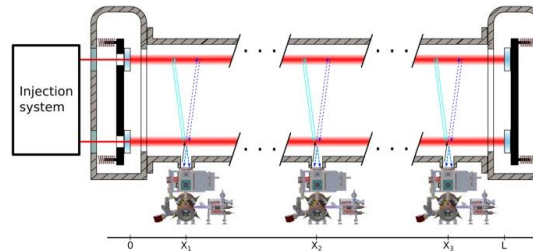
- New frequency range (0.03 – 3 Hz), complementing the program of 3G laser interferometers
- Cosmological sources, early universe physics
- Multi-messenger astronomy: optimal band for sky localization



International efforts in long baseline atomic sensors

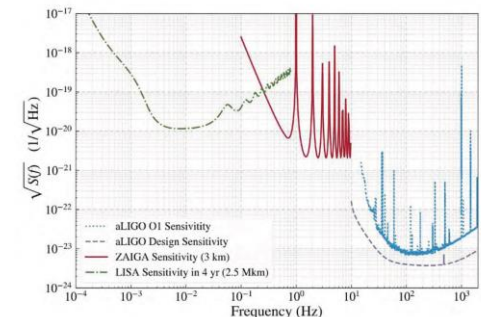
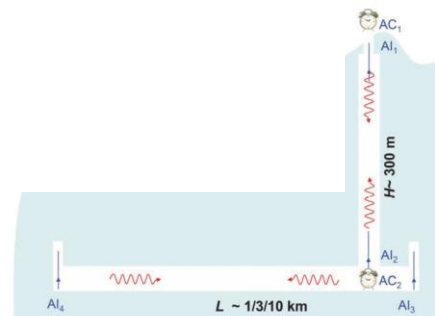
Project	Baseline Length	Number of Baselines	Orientation	Atom	Atom Optics	Location
MAGIS-100	100 m	1	Vertical	Sr	Clock AI, Bragg	USA
AION	100 m	1	Vertical	Sr	Clock AI	UK
MIGA	200 m	2	Horizontal	Rb	Bragg	France
ZAIGA	300 m	3	Vertical	Rb, Sr	Raman, Bragg, OLC	China

MIGA: Matter Wave laser Interferometric Gravitation Antenna (France)



AION: Atom Interferometer Observatory and Network (UK)

ZAIGA: Zhaoshan Long-baseline Atom Interferometer Gravitation Antenna (China)



Next 10 years

Atom interferometry and MAGIS science recognized as a *Priority Research Direction* in the 2020 DOE BRN report on HEP (PRD 13, Thrust 2)

[https://science.osti.gov/-](https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf?la=en&hash=A5C00A96314706A0379368466710593A1A5C4482)

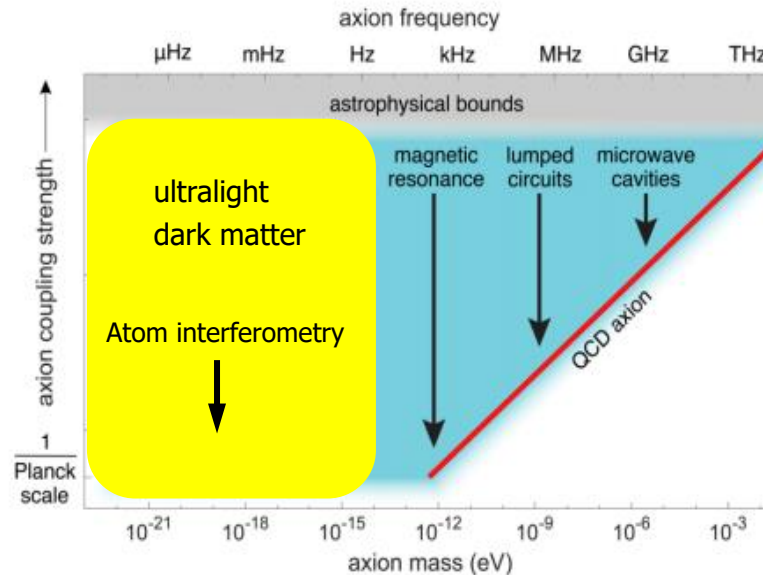
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- Ambitious scope of the current long-baseline atomic experiments is evidence of the enthusiasm in the international community for the long-term science prospects of this technology
- **Next step** is to kilometer-scale baseline; ~\$100M projects will require broad international support
- The path from current 100 m to >1 km baselines will enable the exploitation of the enormous physics potential of ultra-light dark matter and mid-band GW detection, with outstanding opportunities for transformative advances in our understanding of the universe
- Broad community involvement could lead to a LIGO-like collaboration in ~10 years

Ultralight Wave-like Dark Matter

Detection of ultralight, wave-like dark matter requires a **new type of detector** capable of sensing the effects of extremely small, time-dependent, low frequency waves: **large-scale atom interferometers**

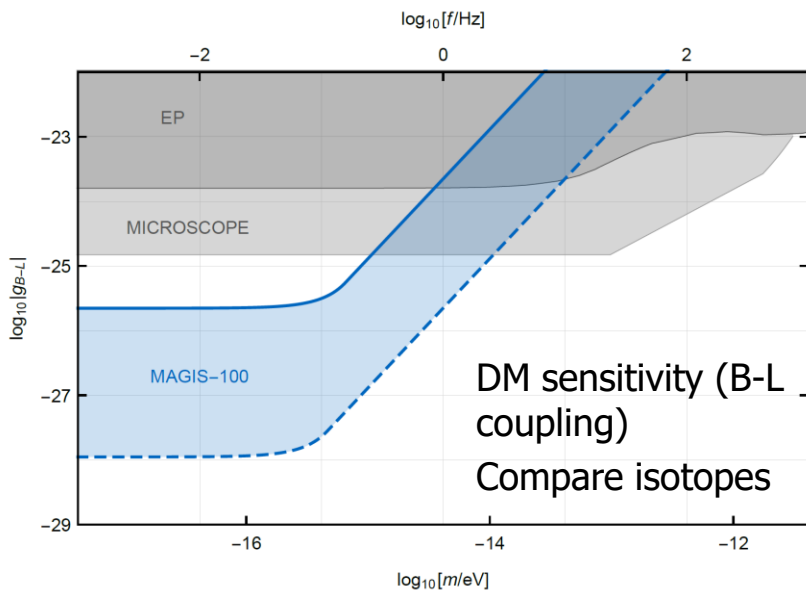
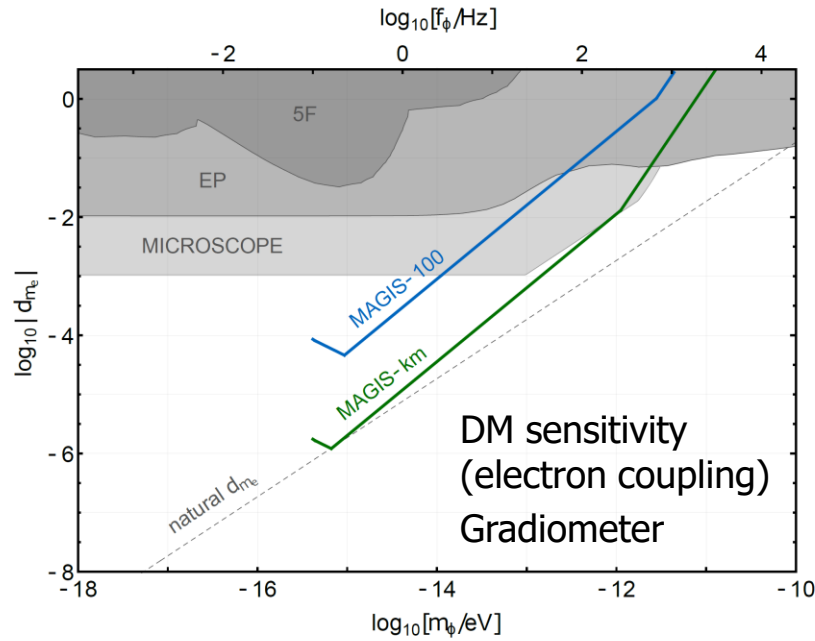
In this mass range, DM acts like a classical field oscillating at a frequency set by its mass



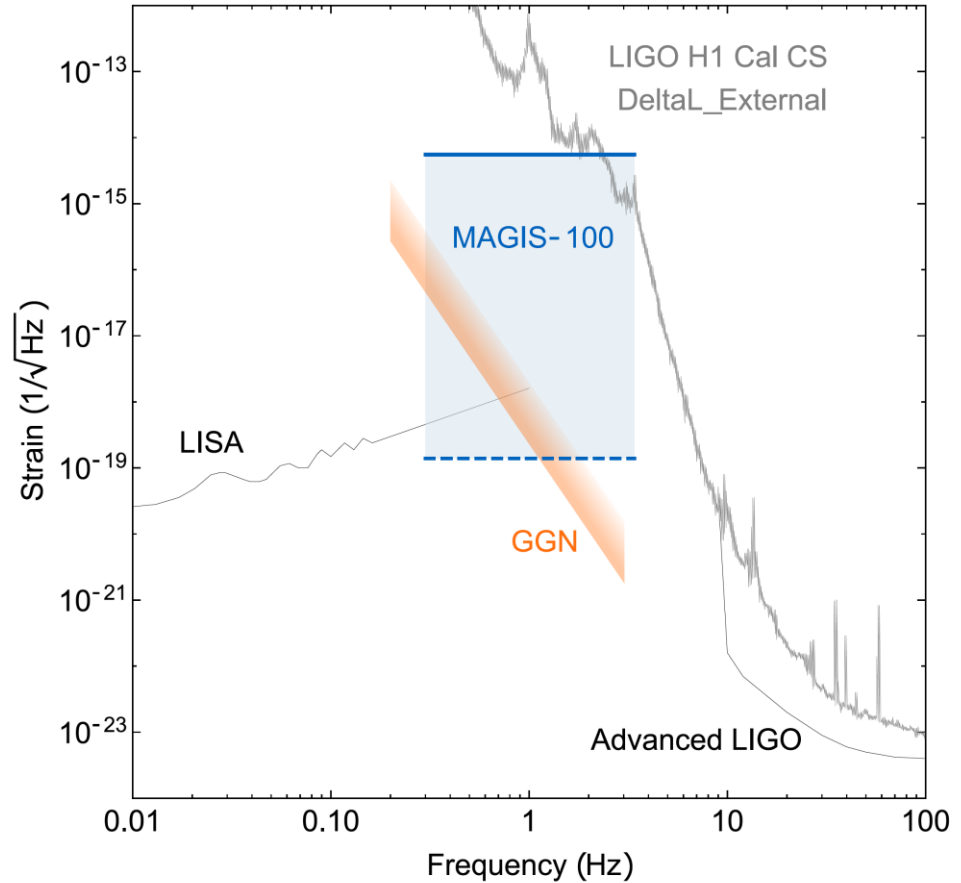
BRN report

- Wave-like DM can lead to time-dependent signals (energy shifts and forces) in high precision quantum sensor networks, enabling a unique probe of its existence
- Search for ultralight dark matter candidates with $m < 10^{-14}$ eV beyond the reach of existing and planned experiments
- Scalar- and vector-coupled DM such as axion-like-particles, the relaxion, B-L coupled vector
- Broad science: can also search for (static) new forces arising from these same interactions, as well as modifications of quantum mechanics and gravitational wave science *with the same instrument*

MAGIS-100 projected sensitivity



Gravitational wave sensitivity



Summary

- MAGIS-100: 100-meter-scale experiment is under construction
- International community is developing long baseline atomic sensing for HEP science
- Several community reports have recognized that long-baseline quantum sensor networks have a broad scientific potential
- **Next 10 years:** Construction of kilometer-scale detectors as part of an international network of sensors to enable transformative searches for ultralight wave-like dark matter, new forces, quantum science, and gravitational wave detection in an unexplored frequency range

MAGIS-100 Collaborators

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GBMF7945

QuantiSED 2019

