HELMHOLTZ

MATTER AND THE UNIVERSE MU

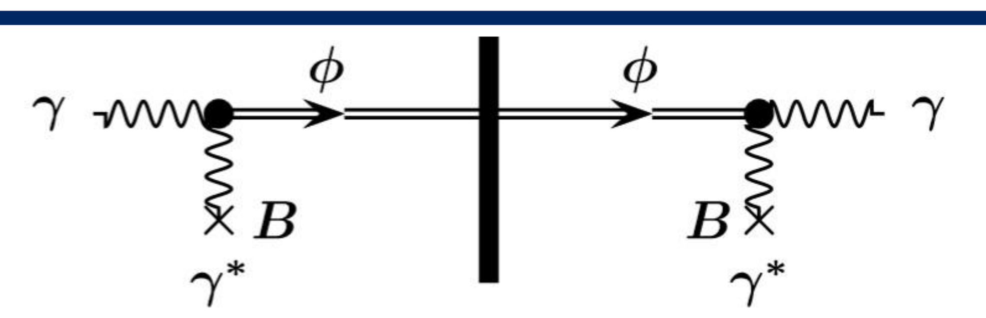
Topic: FPF

Precision Optical Interferometry

for Fundamental Science at ALPS II and Beyond

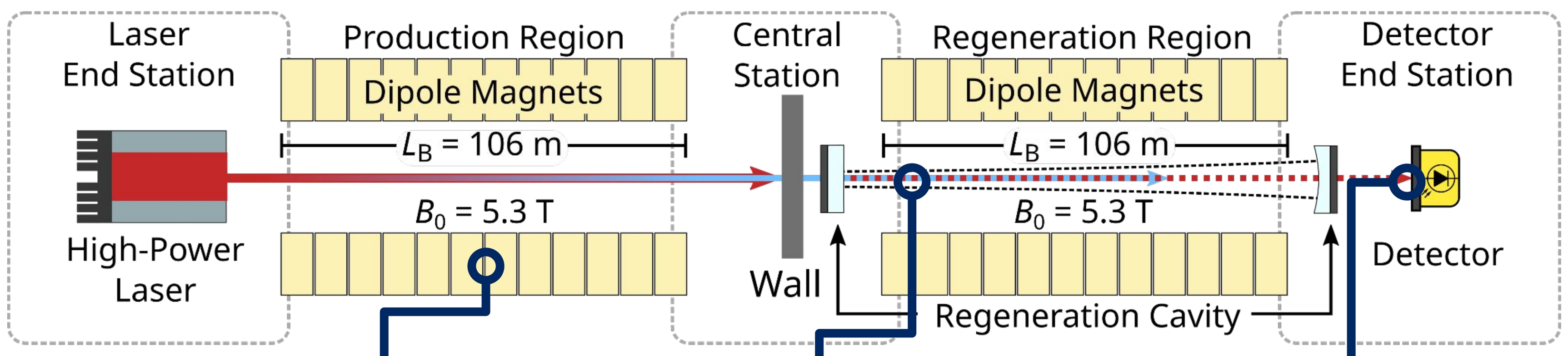
Todd Kozlowski on behalf of the ALPS Optics Group

Light-Shining-through-a-Wall: Laboratory Axion Search

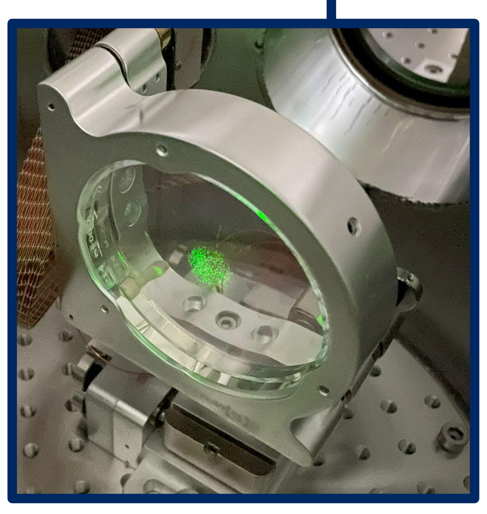


Axions:

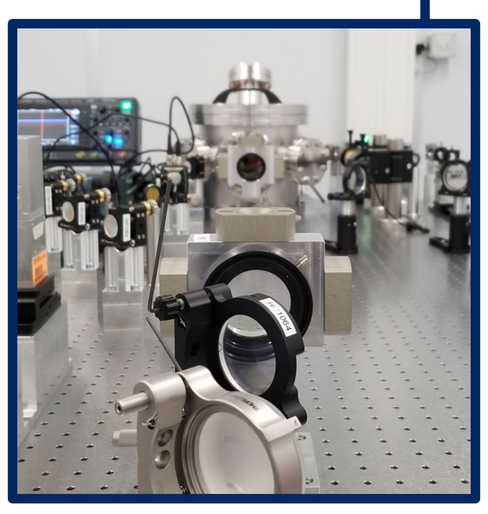
- theoretical lightweight scalar/pseudoscalar bosons
- experimental detection technique: **light shining through walls** [1]



HERA Magnets



Regeneration Cavity



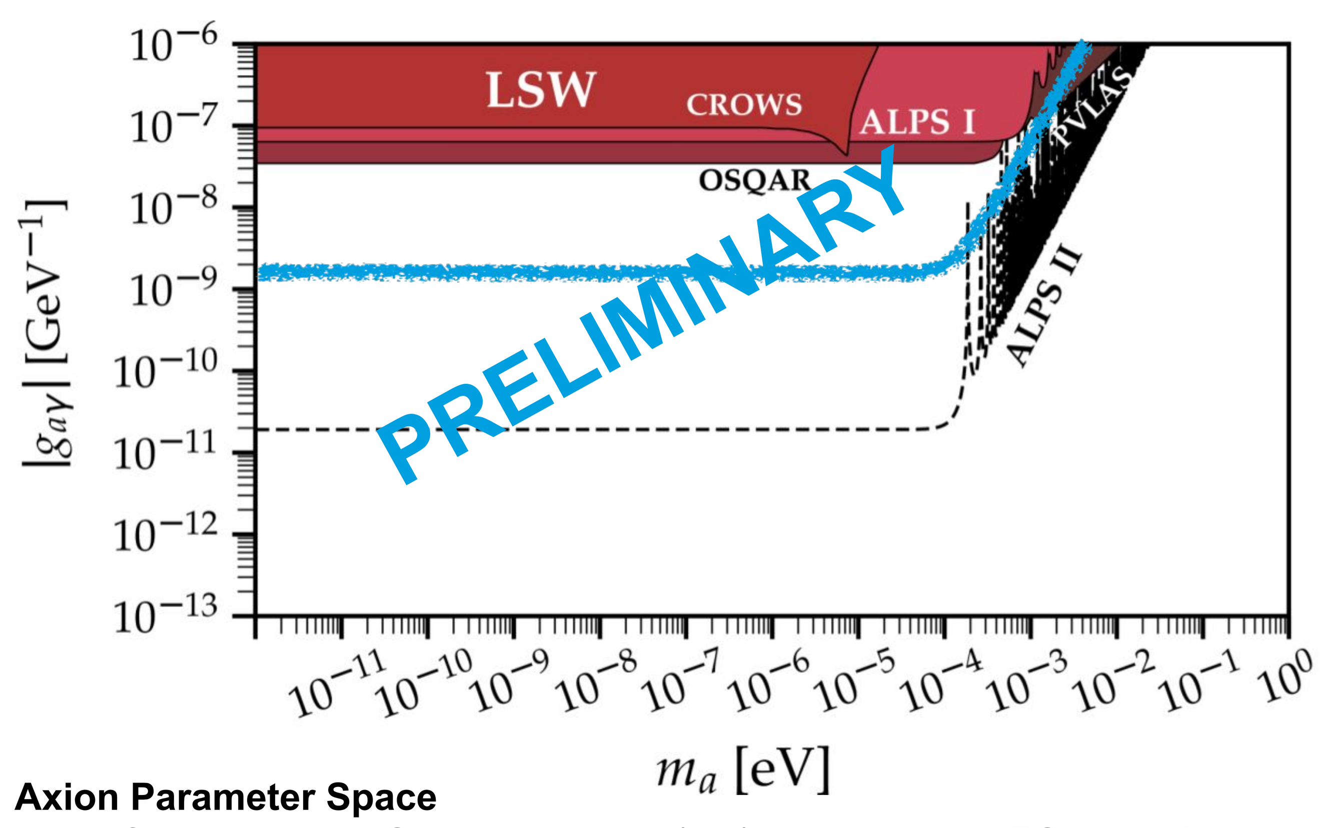
Heterodyne Detector

Unique Infrastructure:

- long-baseline cavity inside a strong B-field: unique in the world
- development of the optics resulted in 6 Ph.D. theses

First results (26.01.2024 to 05.05.2024):

- most sensitive LSW experiment by **factor 1,000,000** in signal rate
- *Production Cavity* to increase signal rate further factor of 3,000



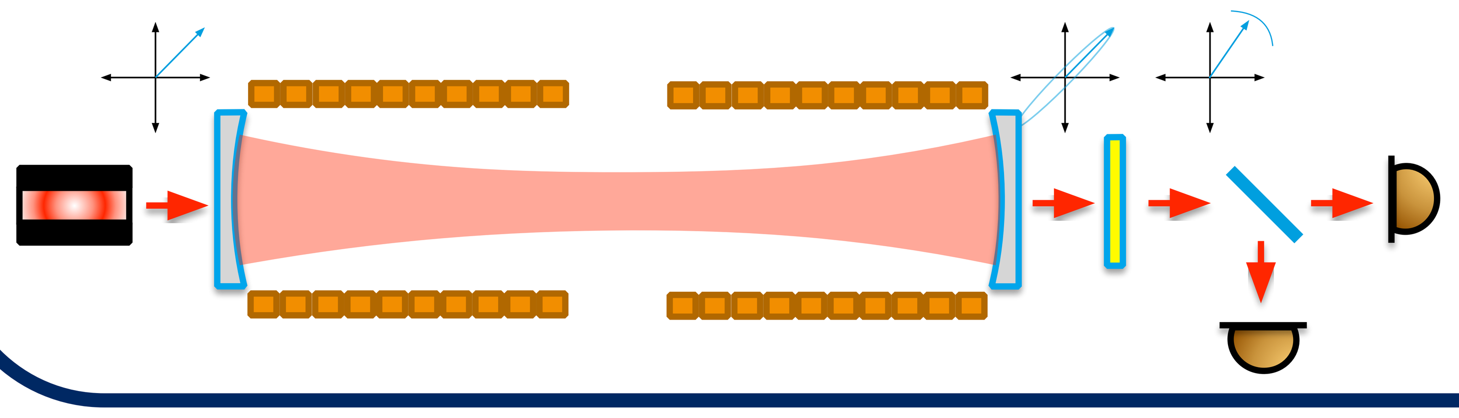
Axion Parameter Space
Limits from previous LSW experiments (red), the current ALPS II sensitivity (blue) and the sensitivity to be achieved in 2025-2026 (black).

Vacuum Magnetic Birefringence: Probing Nonlinear QED Effects

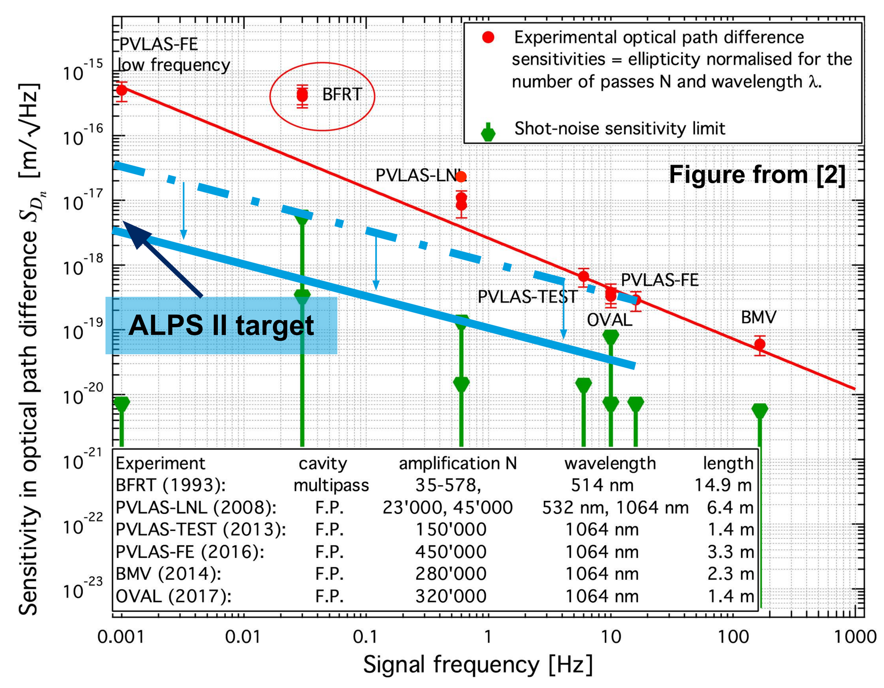
- 60-year-old prediction of QED [2]
- in a magnetic field, the vacuum itself becomes birefringent

$$\Delta n^{(\mathrm{VMB})} = n_{\parallel}^{(\mathrm{VMB})} - n_{\perp}^{(\mathrm{VMB})} = 3A_e B_{\mathrm{ext}}^2$$

- using an optical cavity, relative phase change is amplified



VMB@ALPS II: infrastructure perfectly suited for a probe of the VMB



Experiment	L	$\Delta B^2 L$	f_{mod}	Sensitivity Δn
PVLAS	1.6 m	10 T^{2}m	16 Hz	2e-23 T^{-2}
BMV	0.14 m	5.8 T^{2}m	180 Hz	7e-21 T^{-2}
ALPS II	212 m	**6000 T^{2}m**	3 mHz	?

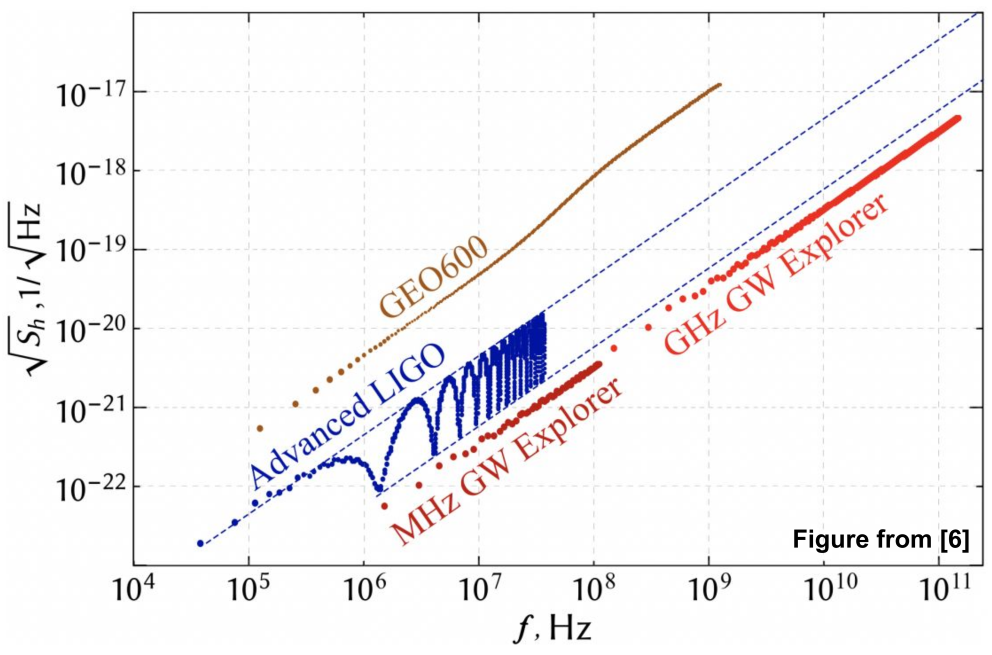
VMB effect strength (above) and **path-length sensitivities** (left) of leading experiments vs ALPS II goals

- after ALPS II data-taking in 2026, hand-off of infrastructure for a VMB search

High-Frequency Gravitational Waves

Traditional Gravitational Wave Interferometry

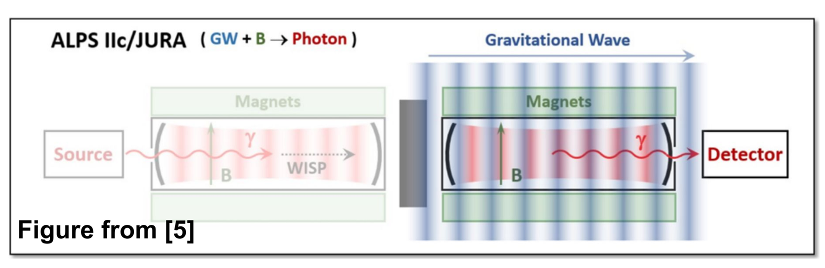
- local expertise in the techniques and technology used in the GW community
- "classical" GW detectors regain sensitivity at higher cavity resonances



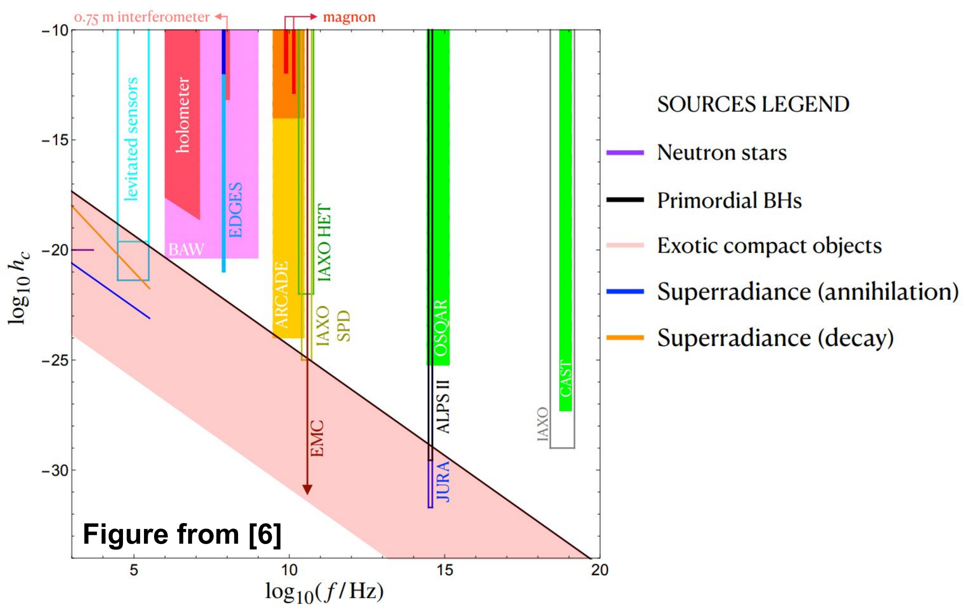
Shot-noise spectral densities for existing GW detectors and potential "GW Explorer" experiments [3]. The optics in ALPS II are of a type suitable for 100-m scale arm cavities for a "MHz GW Explorer".

Ultra-high Frequency GWs from the (Inverse) Gertsenshtein Effect

- direct coupling of gravitational to EM waves in a magnetic field via the *Gertsenshtein Effect* [4].



- at resonant optical frequencies (~300 THz), converted EM waves are enhanced by the cavity

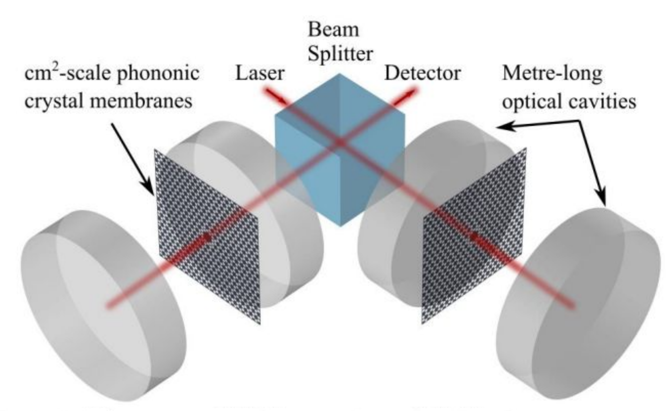


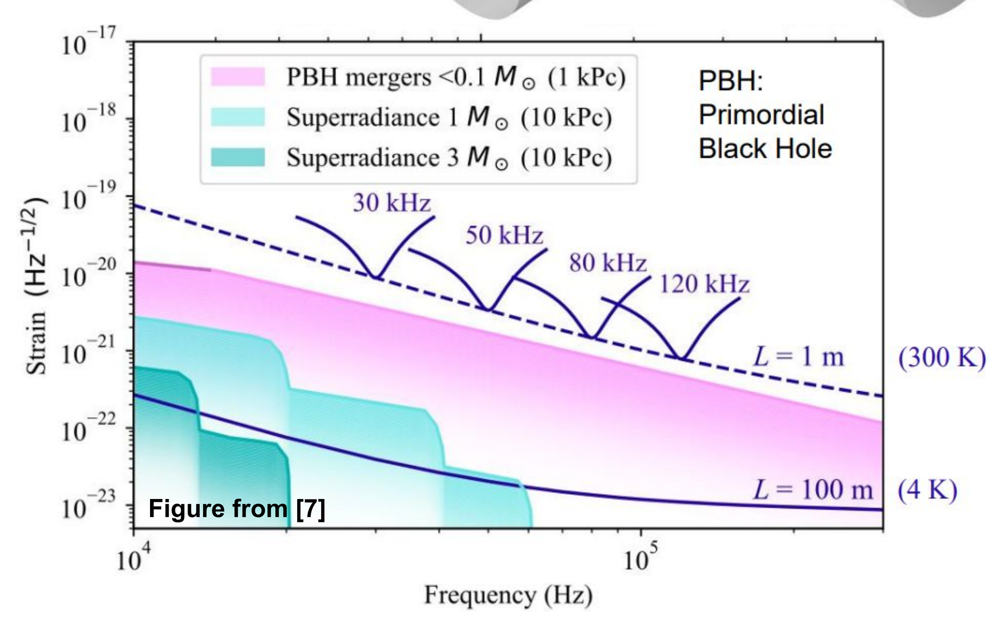
Projected Sensitivity of modern and future experiments.

Levitated Sensor-Enhanced GW Detection

- optically trapped membranes provide a resonant enhancement if the gravitational wave frequency coincides with a (tunable) mechanical resonance

Membrane Detector uses a *trapping field* and a *probe field* to read out resonantly-enhanced GW signals





Projected Sensitivity of a membrane GW detector.

Partner Institutions:

UF University of Florida · UHH Universität Hamburg · Cardiff University / Prifysgol Caerdydd · SDU · Leibniz Universität Hannover · DESY

[1] Diaz Ortiz, M. et al., Physics of the Dark Universe, 35 (2022).
[2] Ejlli, et al., Physics Reports 871, 1-74 (2020)
[3] Schnabel, R. and Korobko, M., arXiv:2409.03019 (2024)
[4] Gertsenshtein, M. E., J. Exptl. Theoret. Phys. (USSR) 41, 113-114 (1961)
[5] Ejlli, A. et al., Eur. Phys. J. C 79, 1032 (2019).
[6] Aggarwal, N. et al., PRL 128.11 (2022)
[7] Reinhardt, C., Quantum Sensing for Fundamental Physics (talk)