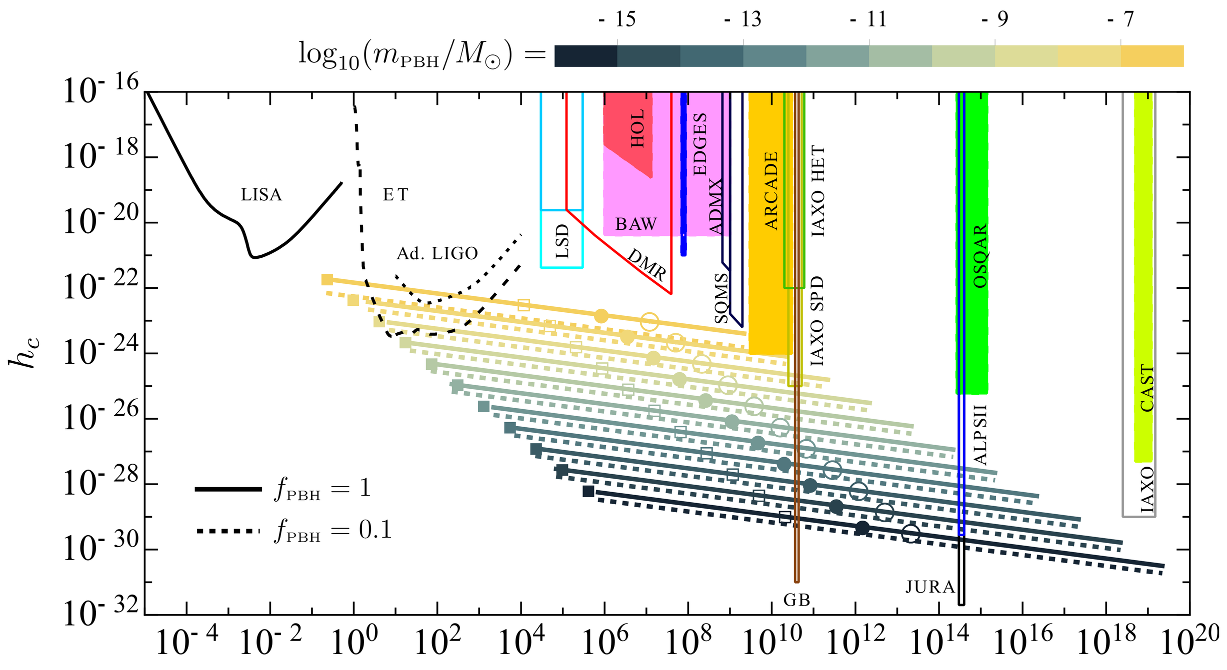
Opportunities for Local High-Frequency Gravitational Wave (HFGW) Experiments

Report FH Gravitational Wave Study Group [Behnke, Grojean, Lindner, Moortgat-Pick, Peters, Reinhardt, Ringwald, Spector]

Physics Case for HFGW Searches

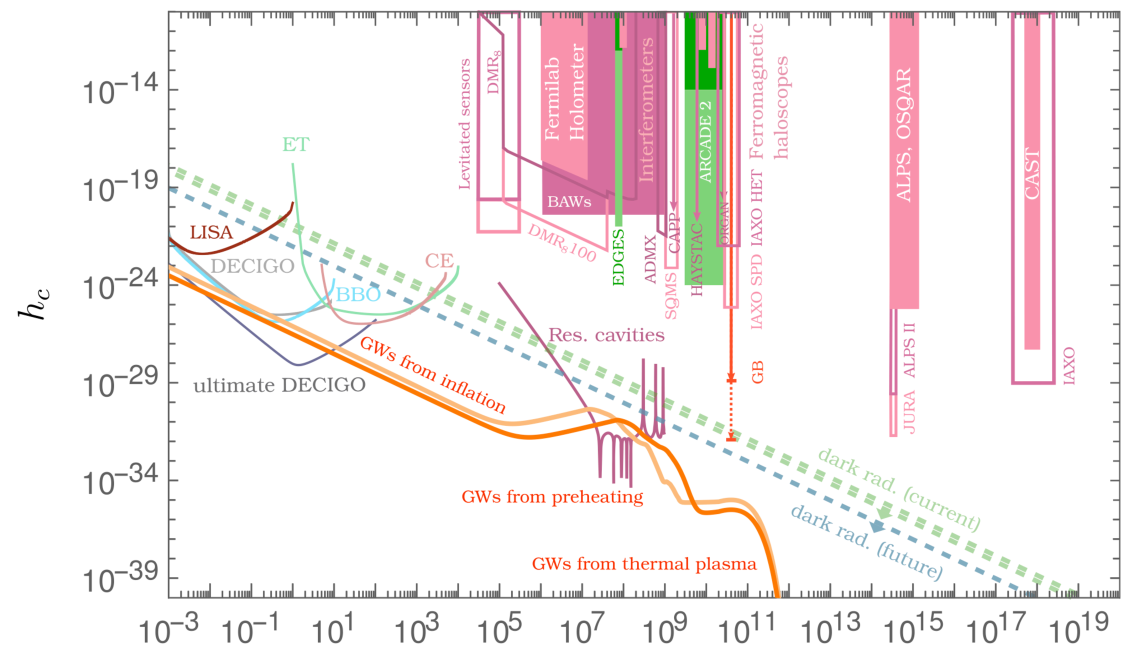
GWs with frequencies above 10 kHz open new avenues for research into some of the most pressing questions in modern physics, notably the nature of dark matter and the cosmology of the early universe

Example 1:
Primordial Black Hole (PBH) Dark Matter (DM) sources HFGWs via merging PBH binaries



Franciolini et al., https://arxiv.org/abs/2205.02153

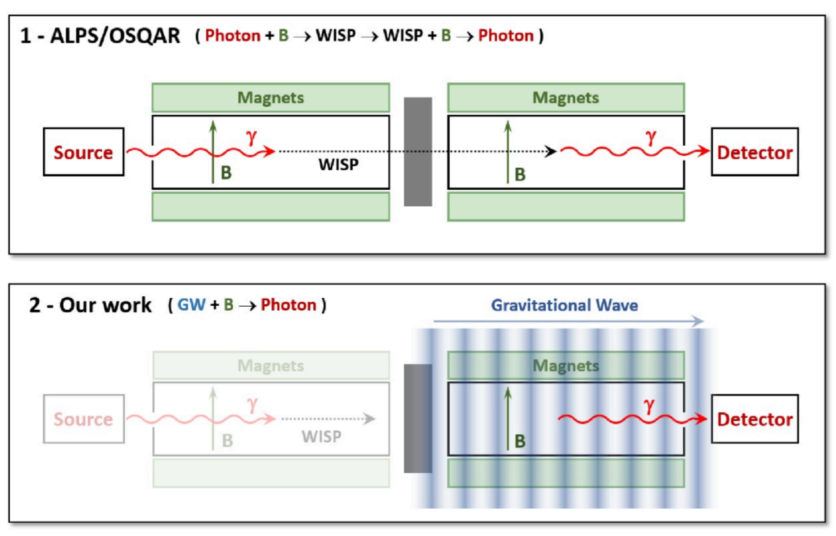
Example 2:
Inflation, reheating and the hot thermal plasma after reheating sources HFGWs



Tamarit,Ringwald., https://arxiv.org/abs/2203.00621

Axion search infrastructure

Light-Shining-through-Wall experiments (ALPS) and helioscopes (IAXO) are sensitive to GWs due to resonant graviton-photon conversion in magnetic fields



Ejlli et al., https://arxiv.org/abs/1908.00232

Unique installation at DESY, unique set of competences within the ALPS II collaboration

Experimental enhancements for GW detection at ALPS

- Option 1: 212m long single optical cavity and single TES broadband detector
- Option 2: Cross-correlating two 106m optical cavities with individual TES detectors to lower statistical noise
- Option 3: No optical cavity, broadband photon detection

Superconducting radio frequency cavities

Resonant Frequency Conversion

- Cavities with frequency ω ~ GHz ≫ ω_G
- If the signal mode is tuned to a frequency $\omega_1 - \omega_0 \approx \omega_G$ (MHz to 0.1 GHz), then the GW resonantly drives power from the pump mode to the signal mode
- Possible to use both detection principles
  - EM-coupling (GW - photon mixing, Gertsenshtein effect)
  - Mechanical coupling (GWs perturb detector)

gr-qc/0502054 Ballantini et al.
physics/0004031 Bernard, Gemme, Parodi, Picasso

Experimental prototype (MAGO)

- Spherical cavities for high Q factor
- Distance between two cells is used to tune ω_G
- Results published in 2005
- Collaboration moved to Virgo due to funding decisions

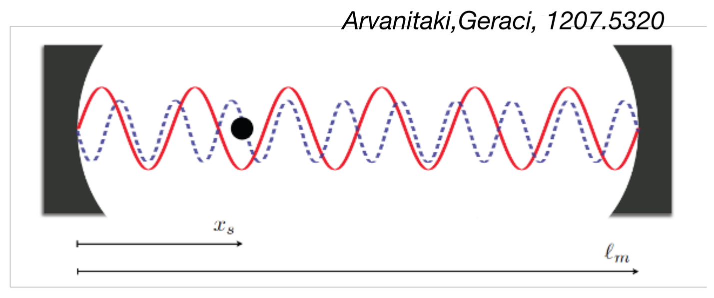
Experimental setup also for Axion detection
Work towards an axion-search prototype at SLAC

DESY Cryoplatform offers a good opportunity as host

Levitated sensors

Trap a dielectric nanoparticle in a laser beam in an optical cavity

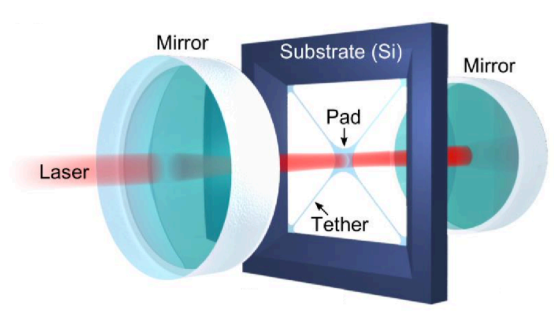
Arvanitaki,Geraci, 1207.5320



GW displaces the disk from its equilibrium position and causes a harmonic restoring force

- Displacement is resonantly enhanced when ωG coincides with trap frequency
- Similar to a resonant bar experiment, but sensor is levitated
- Relatively small sizes of the setups (10~100m)
- Second light field to cool and read out axial position of the levitated object

1-meter prototype under construction at Northwestern University (budget ~ 1M$)
Pilot run planed in ~2y



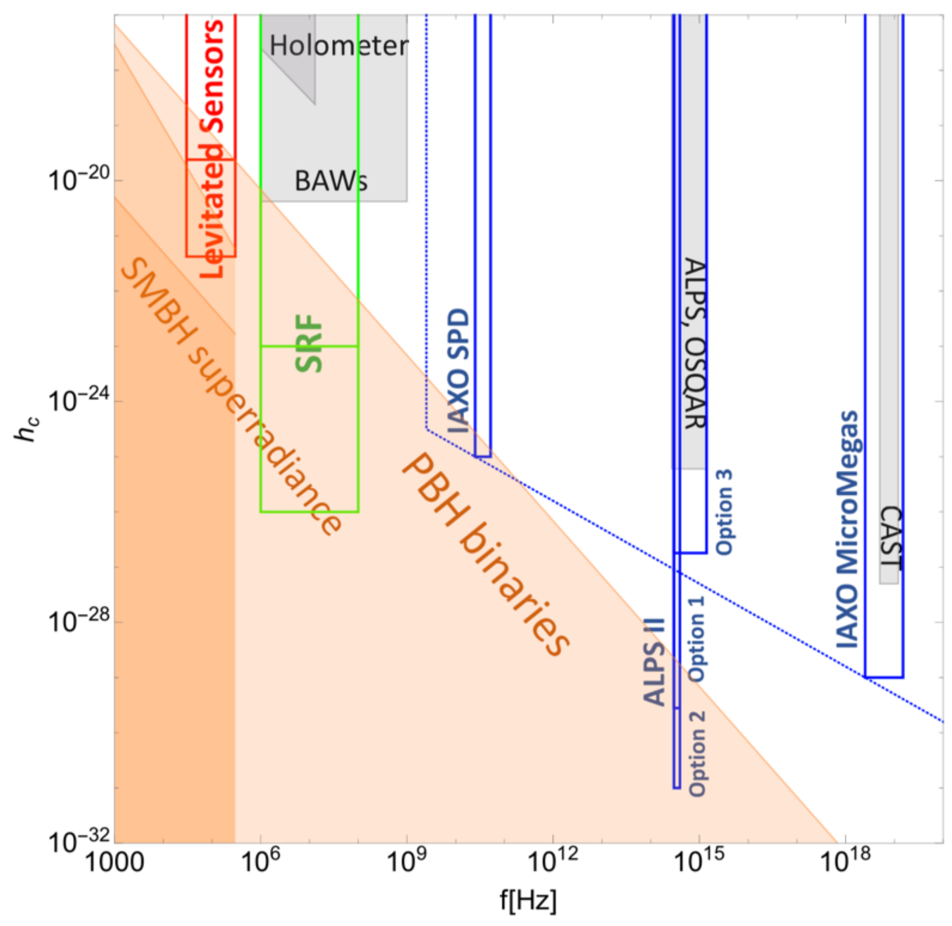
Alternative approach: Partially-levitated membrane

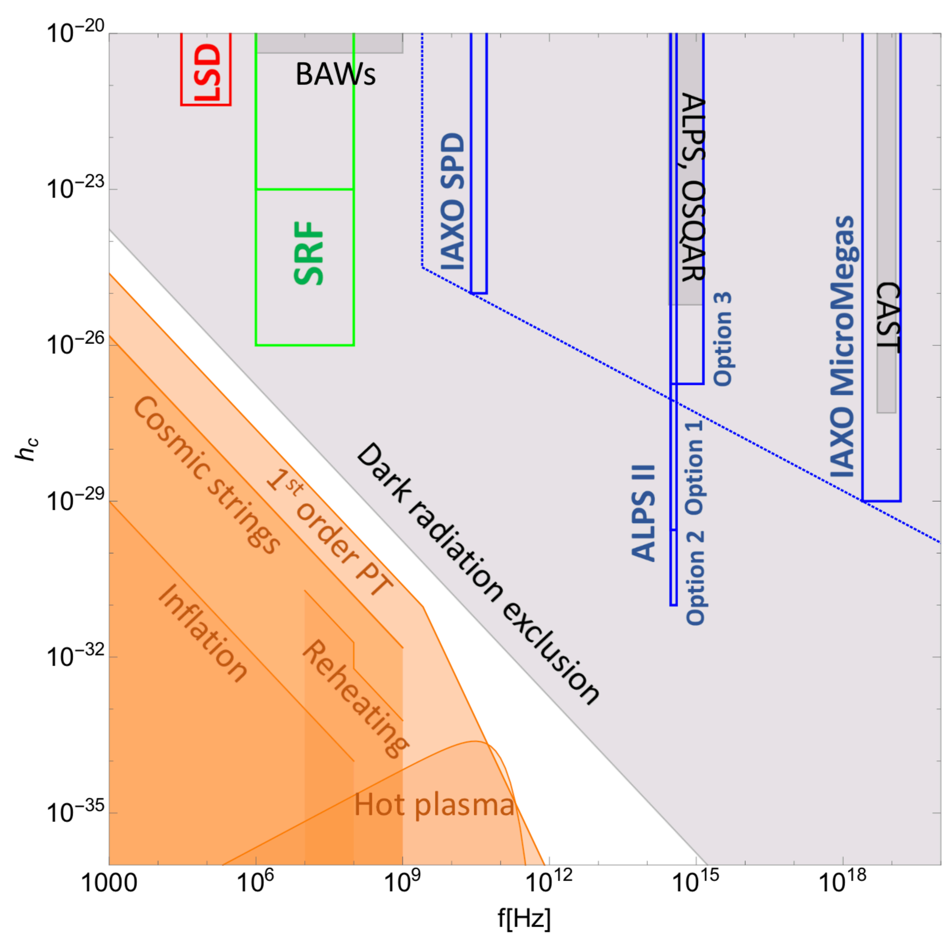
- Membrane Q factor similar to levitated stacks, results in comparable sensitivity
- Allows to reduce mirror radius, enabling to rely on established mirror technology
- Membrane's connection to a substrate enables straight forward handling and installation in the cavity

Current ALPS location would allow for a 100m scale experiment. For a Michelson set-up extend a shorter arm into the HERA hall

Summary

Dedicated GW searches would be a natural follow-up after the axion search programme at ALPS II. While the levitated sensors and SRF cavities still require main R&D efforts, they would add substantial sensitivity and would reach out to a wider frequency range to be probed.





HELMHOLTZ