Search for Gravitational Waves using a Network of RF Cavities

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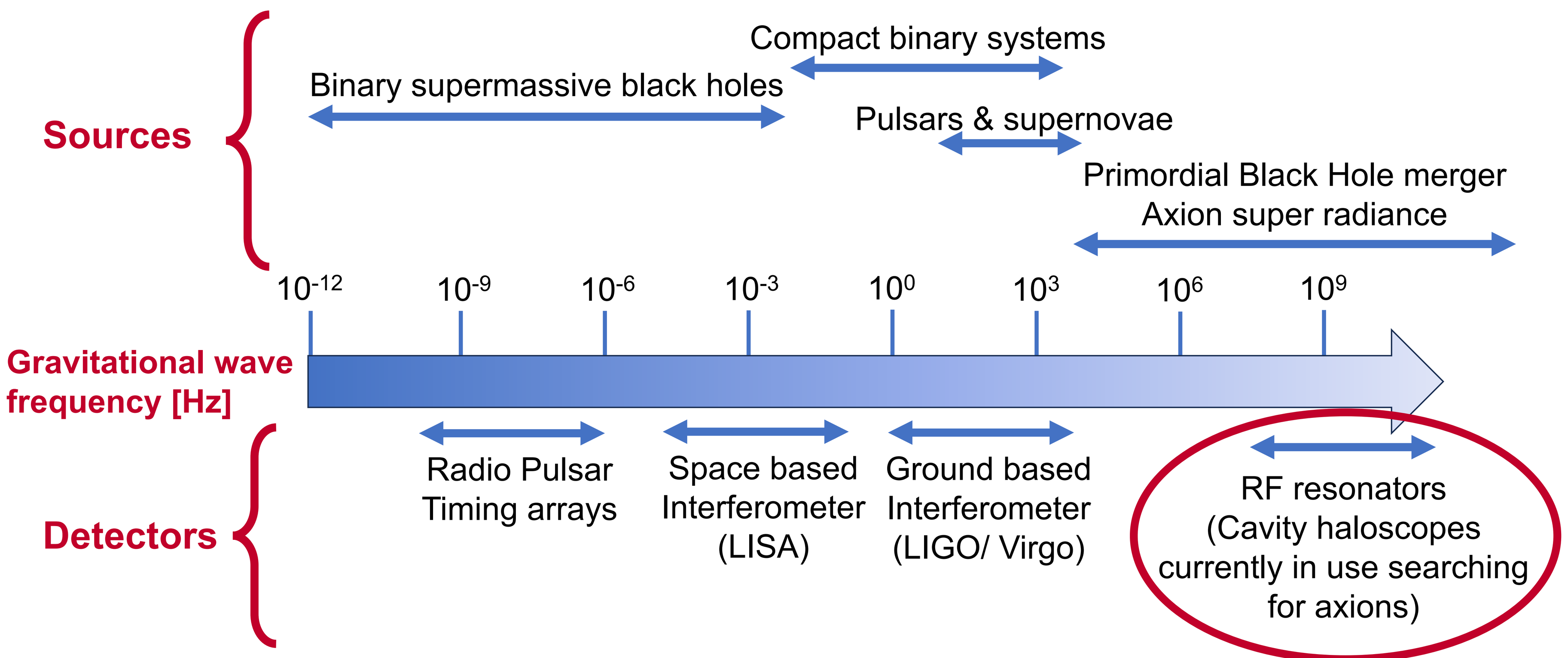
Motivation



Cavity haloscopes

- Usually used to search for halo DM such as axions
- Mass peak of axions is enhanced by cavity resonance
- Conversion into photons by interacting with external B-field → power access
- Could also be used to search for GW signatures of PBH mergers
- Many axion haloscope experiments recast axion limits into GW strain limits
  - Limitation on integration time often neglected (you can't use several minutes - or even hours - of integrated data for signals which are fractions of sections long)
  - Recasts must consider signal coherence time when analysing integrated data in frequency realm (as is usual in axion searches)

	Axions	GW signal of PBH merger
Nature & Orientation of excited cavity eigenmode	Dipole, always along axis of external B-field	Quadrupole, orientation along propagation of GW
Conversion into photons via	Primakoff effect	inverse Gertsenshtein effect
Signal strength	~ $Q_0 B_{ext}^2$	~ $Q_0 B_{ext}^2$
Signal integration	Coherent signal at constant frequency $f \sim m_a$ dependent on axion rest mass	Transient signal, moves through the frequency band

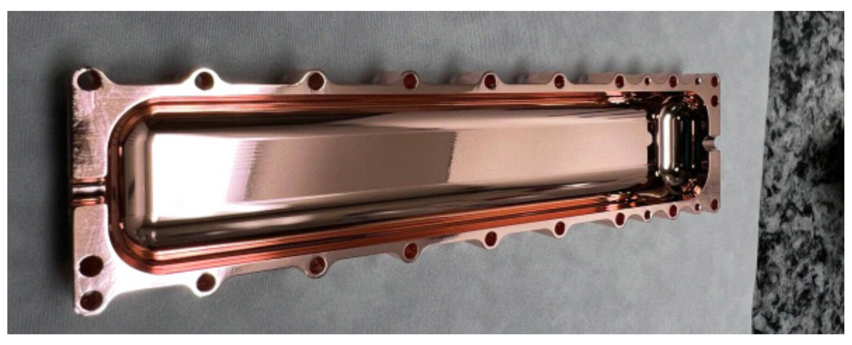


FIG. 1 Rectangular Copper cavity, used for axion search[1]

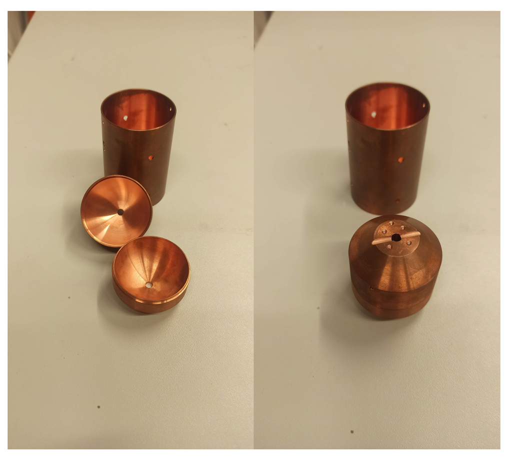


FIG. 2 Spherical cavity, used for GW search

Existing Experimental Setup

- Setup is in dual use
  - while cool down and when cold: vector network analyzer (VNA) attached to track peak position and characterize setup
  - Once characterized: real-time spectrum analyzer can take data in continuous read (no power input, just thermal noise of the cavity)
- Most components commercial off the shelf products
- Cool down + ramping of magnet to max. field ~ 3h each

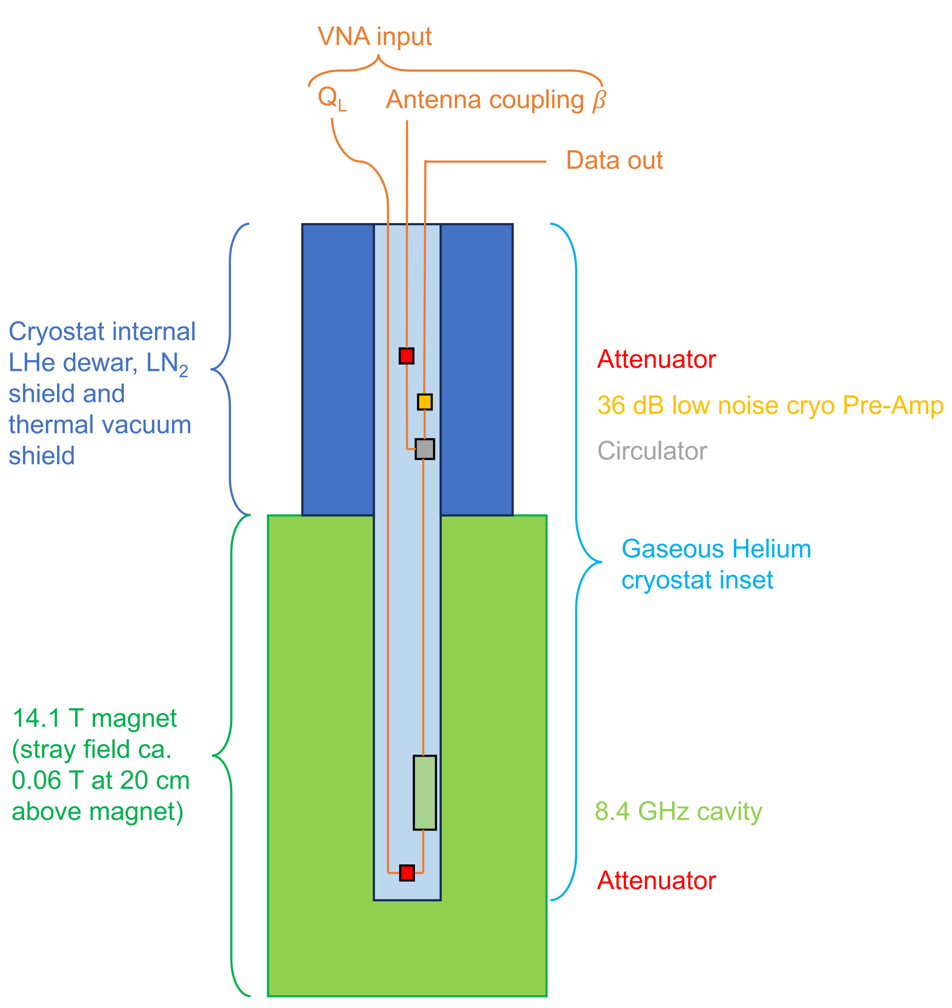


FIG. 3 Setup in use for axion and dark photon search in Mainz, Germany

Sensitivity of existing cavity experiments

- Source: merger of inspiraling primordial black holes
- Expected sensitivities in GHz regime (SQMS, ADMX, etc.) several orders of magnitude away from theoretical models
- While detector development (Q-factor improvement, higher B-field, more volume) will help, a new approach to analysis might be necessary

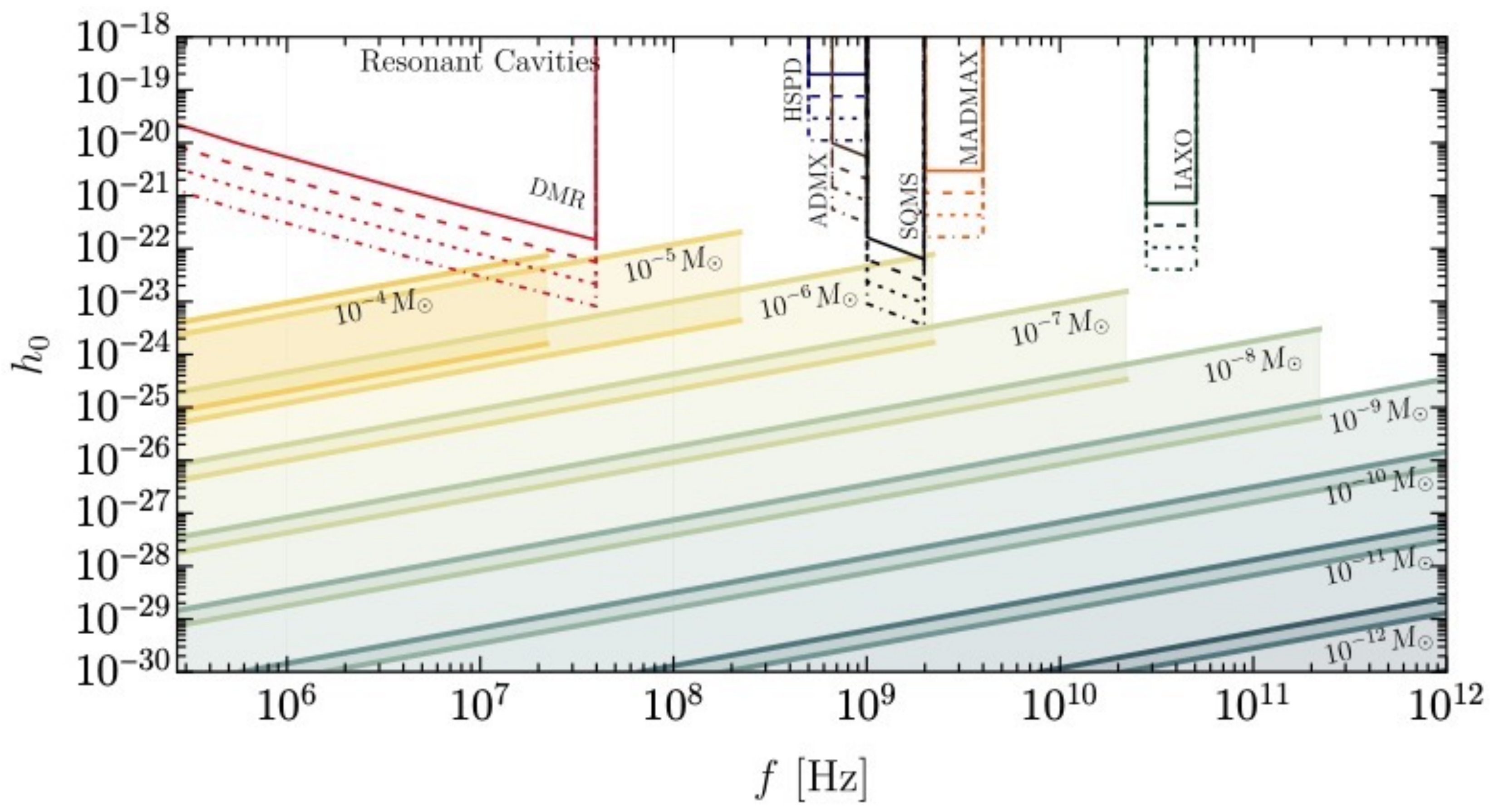
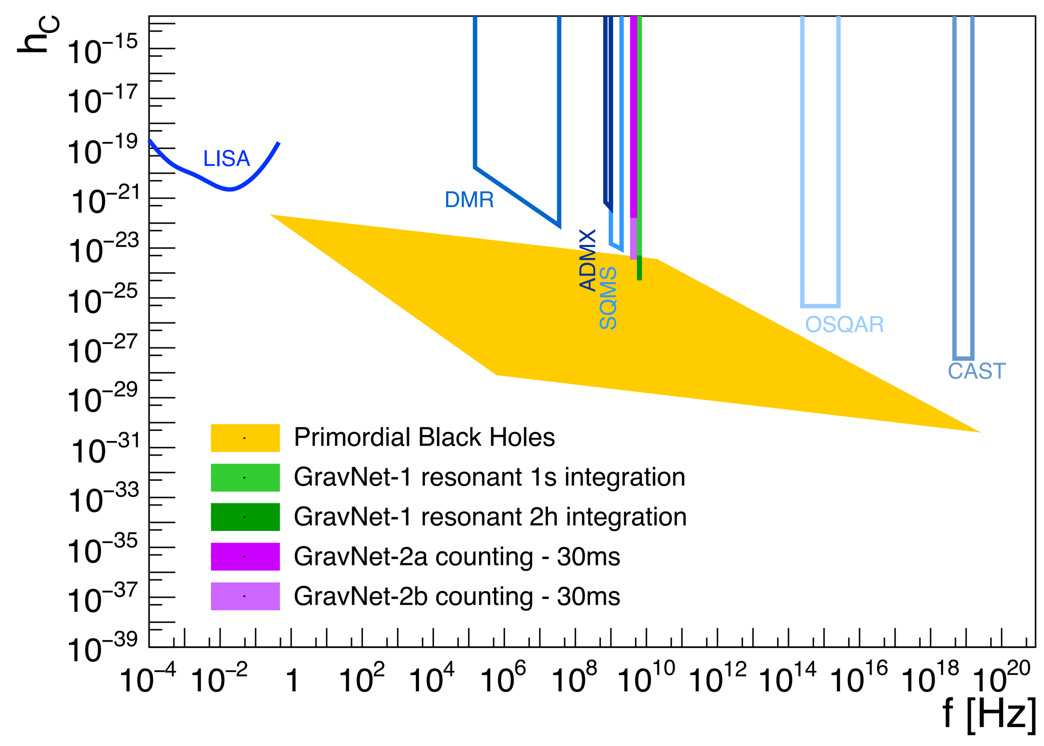


FIG. 4 Expected sensitivity of different experiments, considering the longest integration time dictated by the maximum integration time in the detector. For the GHz experiments ADMX and SQMS the dashed lines are $m_{PBH} = (10^{-9}, 10^{-10}, 10^{-11}, 10^{-12}) M_\odot$ and $m_{PBH} = (10^{-10}, 10^{-11}, 10^{-12}, 10^{-13}) M_\odot$ respectively[2]

The GravNet[3] idea

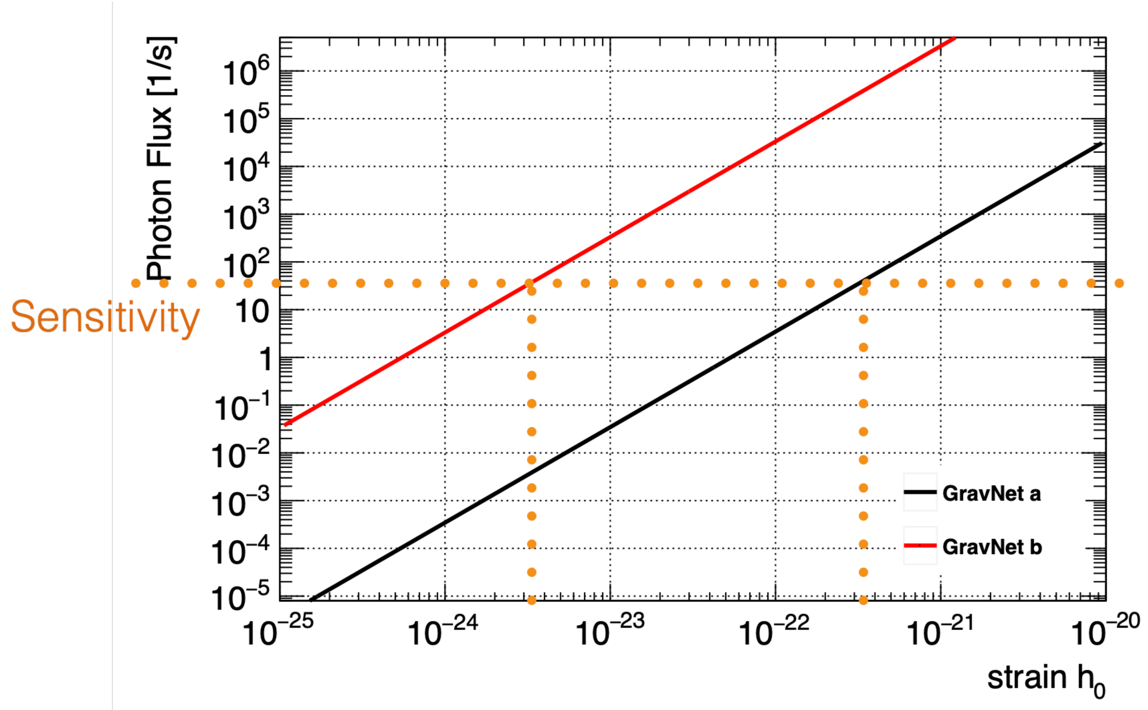
- Use a network of several cavities
- Assuming 10 setups, scattered around the globe
  → combining phase aligned time-series data → effective power increase by factor of 10
  → Strain sensitivity increase by a factor $\sqrt{10} \approx 3$
- Sensitivity $h_0 < 10^{-23}$ at 1s integration time with this setup
- If signal is seen in (at least) 3 cavities the propagation direction of GW can be reconstructed by time delay between the signals



Sensitivity improvement by single photon counter

- Even higher sensitivity possible by single photon counting
- Assuming background rate of 10 Hz (even lower rates have already been achieved – this further improves the following estimates) and 20 detector setups
- Two possible setups:
  a) magnet as in use right now
     B = 14 T & 9 cm diameter
  b) Research NMR magnet
     B = 9 T & 80 cm diameter

Setup	GravNet-a	GravNet-b
radius	40 mm	40 cm
length	12cm	50 cm
Volume $[m^3]$	6×10^{-4}	0.25
Q_0	10^6	10^5
T_{sys} [K]	0.1	0.1
B [T]	14	9



- Achievable sensitivity estimated to be at least: $h_0 < 3 \times 10^{-22}$ ... 3×10^{-24} with 32 ms integration time!
- Does not take into account recent advances on single photon counting techniques

Sources

[1] Tim Schneemann, Kristof Schmieden, Matthias Schott, arXiv:2308.08337
[2] Gabriele Franciolini, Anshuman Maharana, Francesco Muia; arXiv:2205.02153v1
[3] Kristof Schmieden, Matthias Schott; arXiv:2308.11497v1