Motivation

- Compact binary systems
- Binary supermassive black holes
- Pulsars & supernovae
- Primordial Black Hole merger
- Axion super radiance

Sources

Gravitational wave frequency [Hz]

- Radio Pulsar Timing arrays
- Space based Interferometer (LISA)
- Ground based Interferometer (LIGO/ Virgo)
- RF resonators (Cavity haloscopes currently in use searching for axions)

Detectors

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)

<table>
<thead>
<tr>
<th>Axions</th>
<th>GW signal of PBH merger</th>
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<tbody>
<tr>
<td>Nature &amp; Orientation of excited cavity eigenmode</td>
<td>Dipole, always along axis of external B-field</td>
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<tr>
<td>Conversion into photons via</td>
<td>Primakoff effect</td>
</tr>
<tr>
<td>Signal strength</td>
<td>( \sim Q_0 B_{\text{ext}}^2 )</td>
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<tr>
<td>Signal integration</td>
<td>Coherent signal at constant frequency ( / \sim m_a ) dependent on axion rest mass</td>
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<td></td>
<td>Transient signal, moves through the frequency band</td>
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Existing Experimental Setup

- Setup is in dual use
  - white 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 readout (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

- VNA output
  - 3 dB loss noise cryo Pre-Amp
  - Diode
  - Crystal internal Low loss UV, shielded and thermal vacuum shield

- 14-17 copper (magnetic field ca. 0.16 T at 20 cm above magnet)

- 4.4 GHz cavity

- 2 mm bore same cryo Pre-Amp Circulator

- GravNet-b, whose parameters are summarized in Table

Sensitivity of existing cavity experiments

- Source: merger of inspiraling primordial black holes
- Expected sensitivities in GHz regime (SGMS, 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

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 \( h_0 < 10^{-22} \) 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

Sources