Other Physics Targets for BREAD

BREAD Collaboration Meeting 2026 at Harvard

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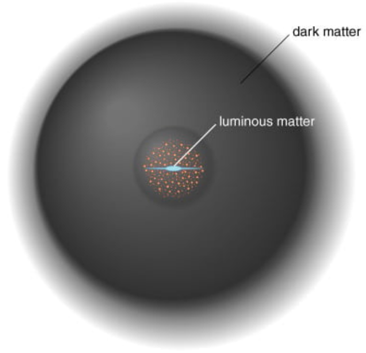
Axion Streams and Miniclusters

What are they?

- The standard halo model assumes a perfectly isotropic dark matter velocity distribution
- There may be substructure which leads to deviations from this.
- Can appear as time-modulations as the relative velocity between earth and a “stream” change during the year.



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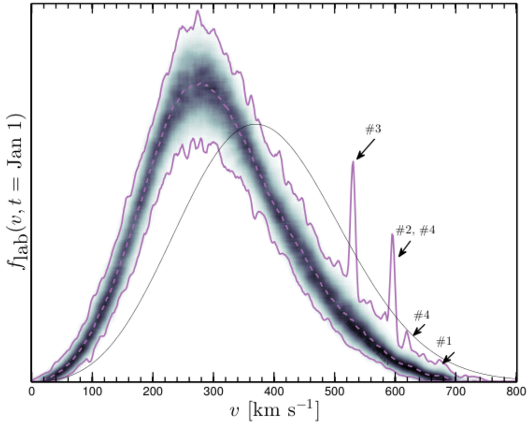
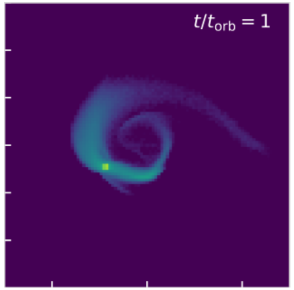


Images from [1], [2]

Types of Substructure

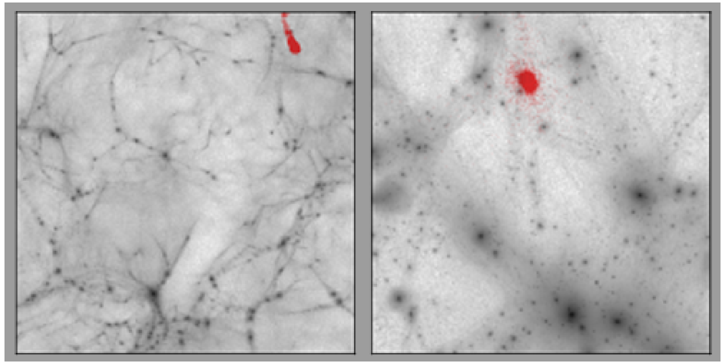
Streams



- Satellite galaxies can leave trails of dark matter due to tidal forces with the main galaxy [2], [3]
- Streams can have a different density and velocity distribution than the SHM axions.

Miniclusters

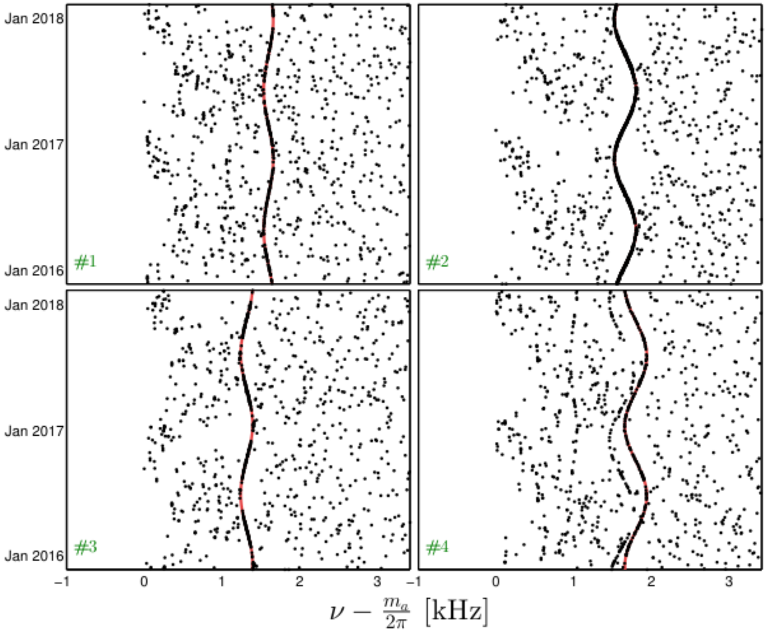
- Overdensities form in the early universe through misalignment and the decay of strings and domain walls and break up into streams due to tidal forces [2]
- Also potentially visible in microlensing surveys [4]



Images from [3], [5]

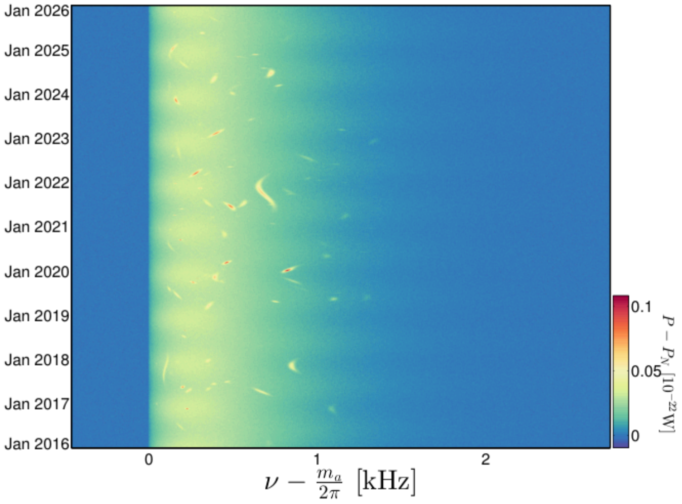
How to Look for Streams and Miniclusters

Streams



- Look for sinusoidal modulation with a period of about 1 year [2].

Miniclusters



- Look for transient signal enhancement which would happen sporadically over a few years [2].

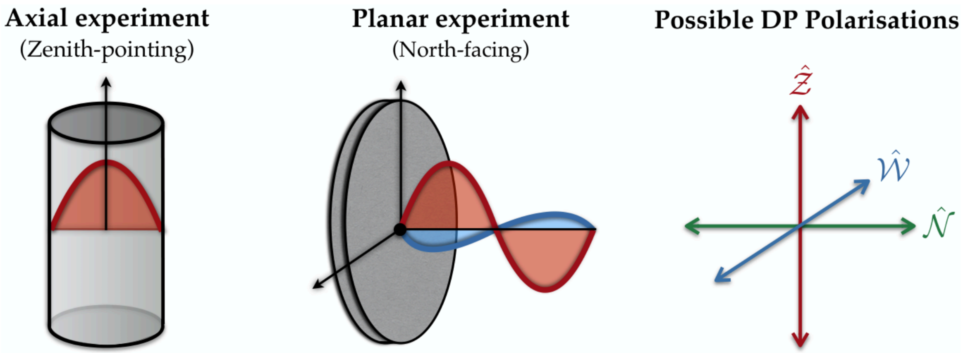
Images from [2]

Search with BREAD

- BREAD may be able to probe the existence of streams and miniclusters even if we don't yet know the axion mass.
- Since we look in a large mass range at once, it is possible that BREAD can perform a search for transients and yearly modulations across a large mass range if we just upgrade the readout to be higher resolution (currently we have 7.8 kHz bins)
- GigaBREAD stored data as a series of time-stamped FFTs which simplifies the search for transients and modulations (see Jialin's talk next).
- Transients may be challenging to distinguish from background so may require a more isolated environment or more detailed analysis (even the short lived signal should modulate with the earth's rotation).

Polarized Dark Photons

Dark Photon Polarization

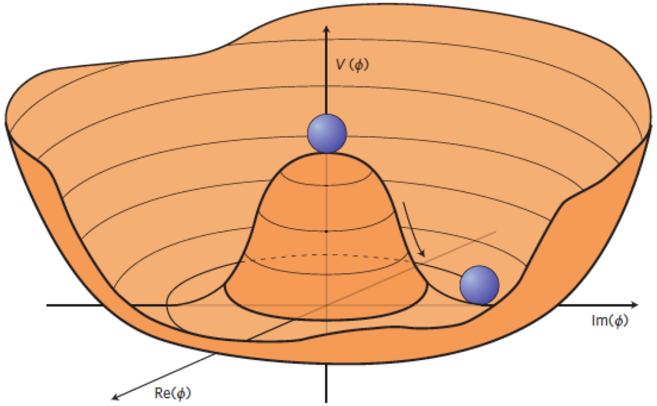


- Unlike axions which are scalars, dark photons are vector bosons and have a polarization (which can even even be longitudinal since they are often taken to be massive).
- Generally experiments assume dark photons are randomly polarized when calculating limits but this may not generally be true and there may be a component of dark photon dark matter which is polarized.

Images from [6]

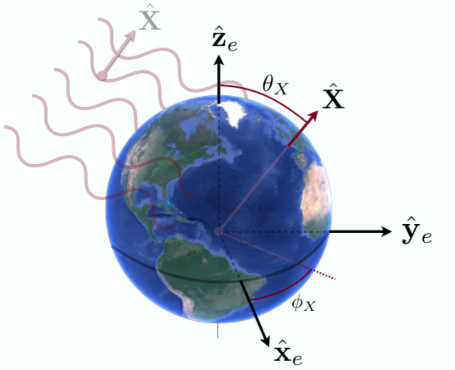
Polarized Dark Photon Production

- Production via the misalignment mechanism or the decay of topological defects produces longitudinally polarized dark matter [6]
- Other production mechanisms are possible but are less straightforward
- After production the coherence of the polarization may get washed out but this isn't well understood. It is at least plausible that a component remains polarized [6].



Images from [7], [8]

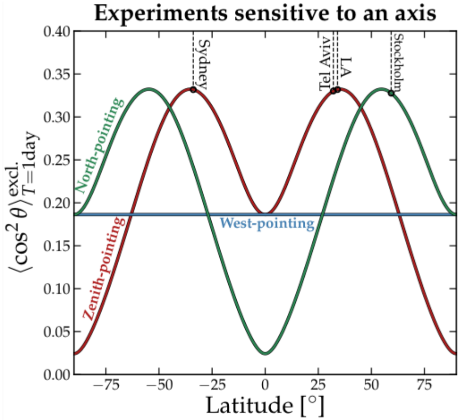
How to Look for Polarized Dark Photons



- The rotation of the earth will modulate the overlap of the dark photon polarization with the polarization axis of the detector

Image from [6]

- This modulation can be calculated based based on the latitude and orientation of the detector
- Jialin has been working on an analysis to look for this daily modulation so check out her talk next!



Cosmic Axion Background

What is it?

- Relativistic axions produced in the early universe analagous to the CMB.
- Distinct from the colder axions which would make up dark matter.
- Much broader lineshape $\frac{\Delta\omega}{\omega} \sim 1$ [9].
- Aside from being an interesting probe of new cosmology, adding a new relativistic light species can also help reduce the hubble tension [9].

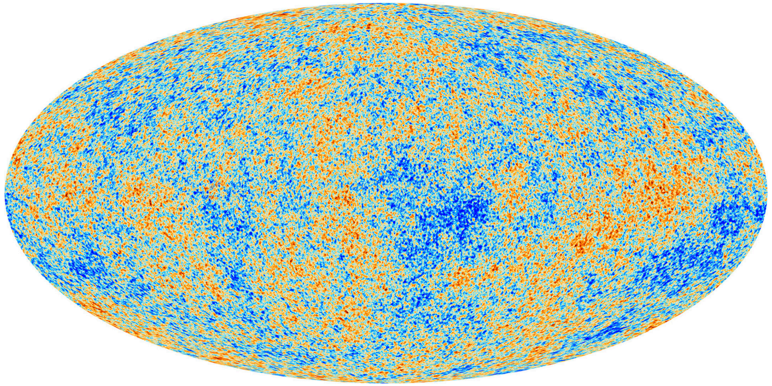


Image from [10]

Sources

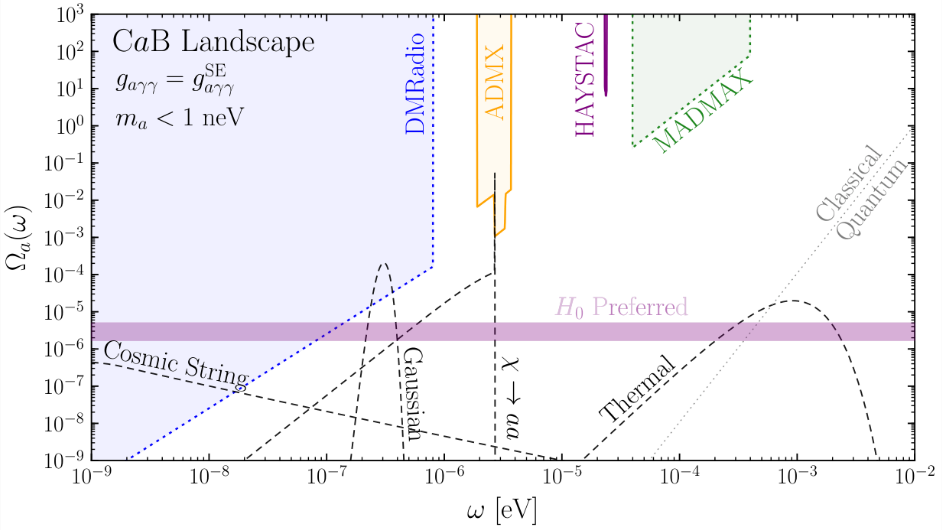


Image from [9]

- CaB axions produced before decoupling from the SM and leaving a thermal relic.
- Decay of heavier dark matter or neutrinos into CaB axions.
- Decay of topological defects.
- Parametric resonance: oscillation of a different scalar field rapidly dumps energy into axions.

Daily Modulation

- Relativistic axions have a much shorter coherence length than axion dark matter.
- Axion coupling will be modulated by the axion momentum with respect to the $\vec{B}$–field.
- Isotropic CaB sources (e.g. thermal relic) will just average out to an isotropic sensitivity
- Sources like DM decay ($\chi \to aa$) may have higher power from the galactic center and Earth’s rotation can induce a daily modulation [11], [9]

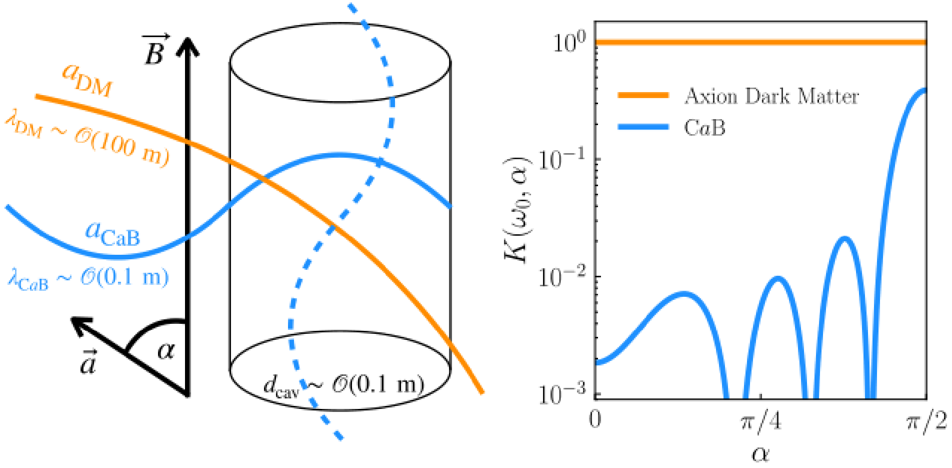
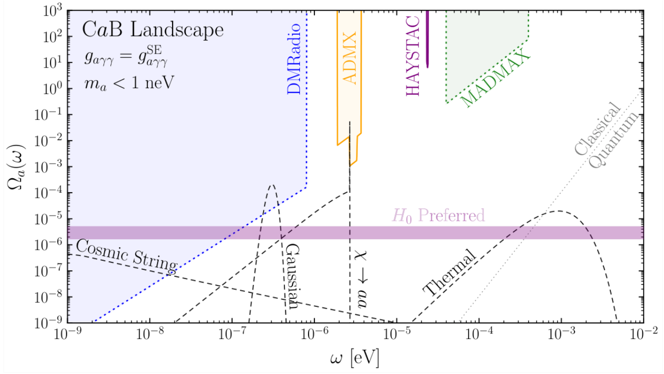
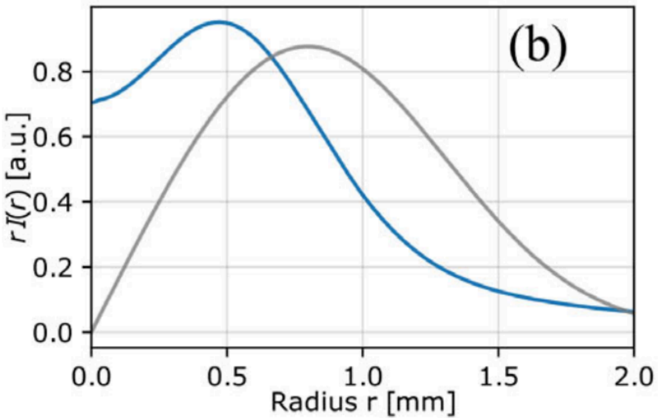


Image from [11]

How to look for CaB

- A broadband measurement may allow us to see CaB lineshape
- If there is a daily modulation of the CaB the time-stamped broadband spectra that were produced for GigaBREAD are very valuable.
- At increasingly higher frequencies the signal at the focal spot can become increasingly smeared which present challenges for sensor choice.





Images from [9], [12]

Axion Quark Nuggets

What are they?

- Stable composite structure of axion domain wall, quarks, and gluons [13]
- Very massive with average baryon number $B \geq 3 \times 10^{24}$ and masses on the scale of grams [14]!
- Coupling is not feeble like most dark matter but since it is massive with low number density interactions are still rare.
- When they pass through earth they lose mass to annihilation and emit relativistic axions.

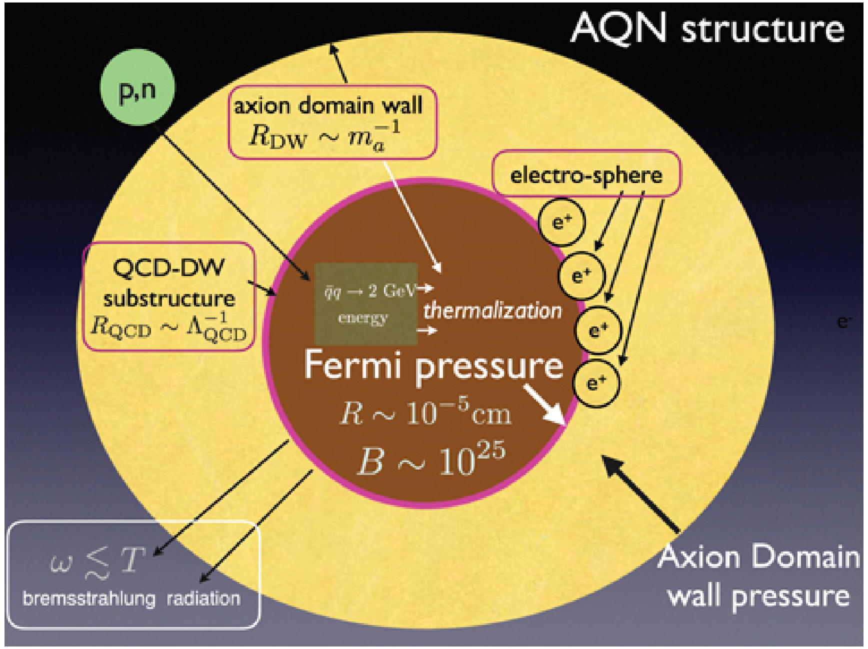


Image from [15]

Daily Modulation and Yearly

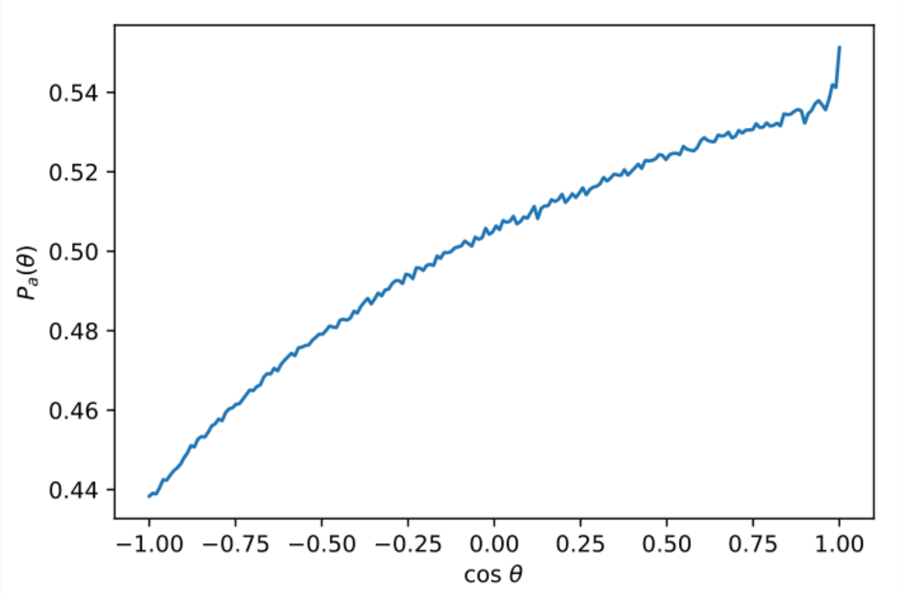
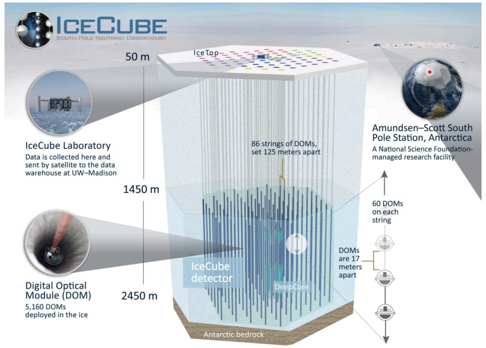


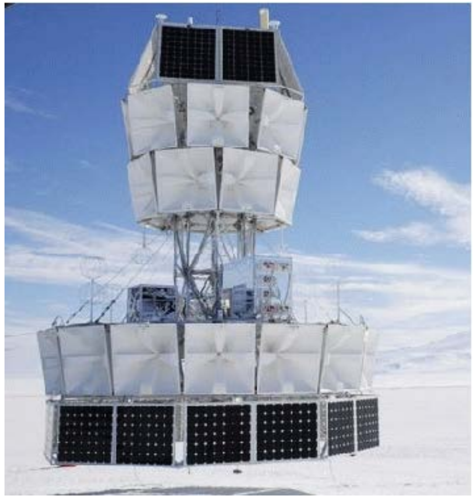
Image from [14]

- AQNs passing through Earth have different masses when they enter vs exit Earth [14].
- Detectors closer to the entry point have higher axion flux.
- The DM wind combined with Earth's rotation and orbit produces a daily modulation and yearly modulation
- This modulation is due to the actual amount of relativistic axion flux. Not any kind of directional coupling to the axions.

How to look for AQN

- Search for daily and annual modulation
- It is estimated that a detector with a 10 m^2 area would see a few single microwave photon events per day assuming a QCD band axion [14].
- Experiments like IceCube and ANITA are sensitive to AQNs [16] so combining detector technologies to look at different channels may be prudent.





Images from [17], [18]

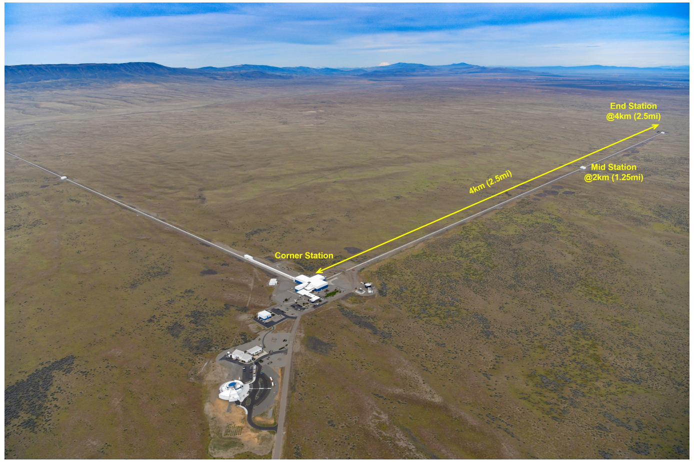
High Frequency Gravitational Waves

Gravitational Waves

Waves in spacetime

- Pulsar timing arrays cover extremely low frequency gravitational waves ∼nHz [19]

- Interferometers like LIGO and VIRGO lose sensitivity above 10 kHz [20]

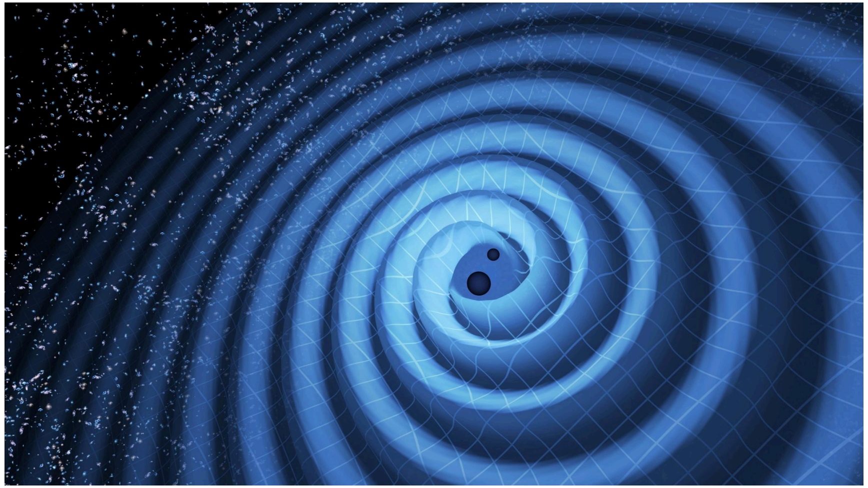


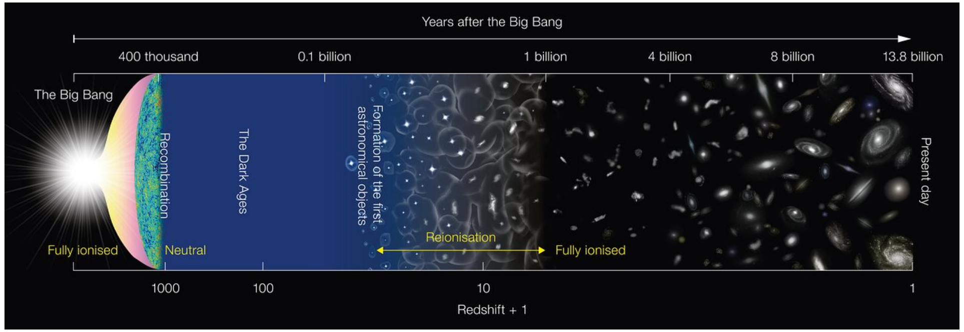
- Different technology is required to push above 10 kHz

Images from [21], [22]

Scientific Motivation

- Gravitational waves with frequencies higher than 10 kHz are potentially produced by primordial black hole mergers and exotic dense objects like bosonic stars [20].

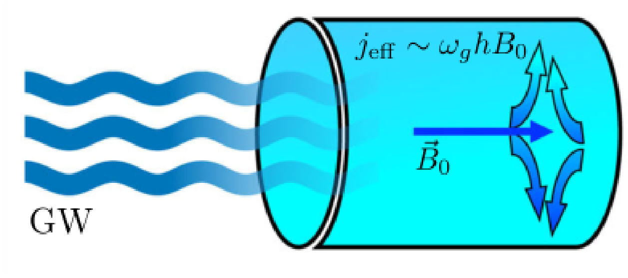


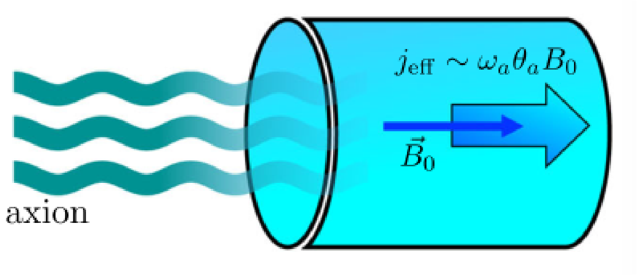


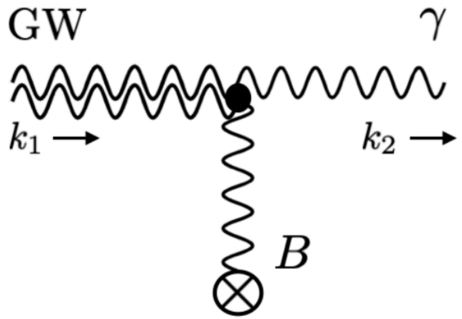
- HFGW could provide insight into the cosmology of the extremely early universe because they would have decoupled earlier than the CMB [20].

Images from [23], [24]

Photon Coupling





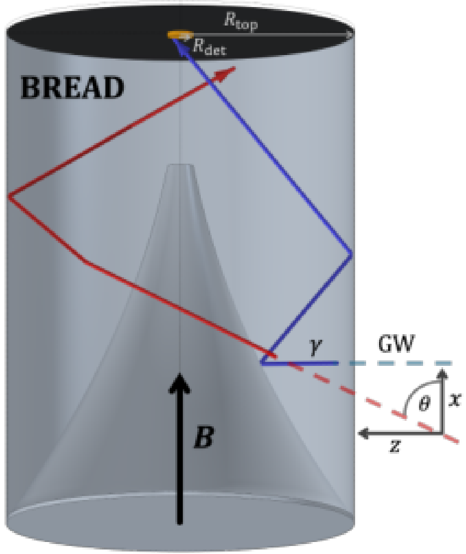


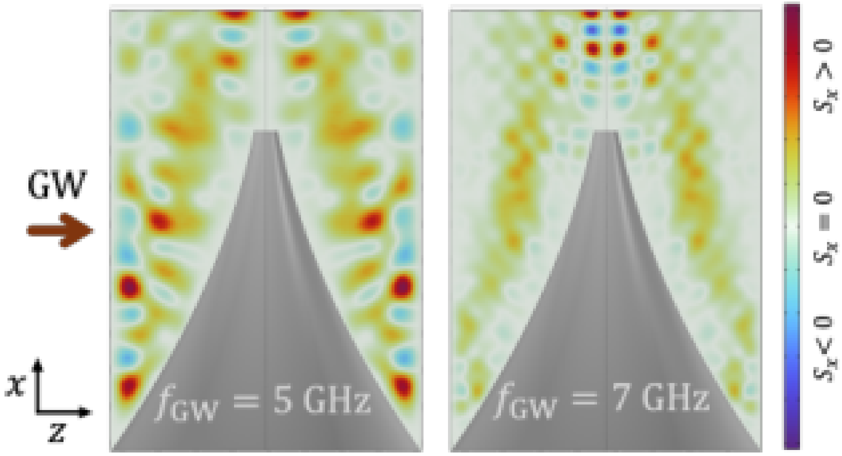
- Gravitational waves have a coupling to photons in a magnetic field like the axion does
- Unlike the axion, however, gravitational waves couple to a quadrupole electric field configuration rather than an electric field which is aligned with the external magnetic field [25]
- This different coupling means that HFGW couple to the whole volume of BREAD and not just the reflector surface [26]

Images from: [26], [25]

HFGWs at BREAD

- Photon trajectory has a large influence from the gravitational wave momentum, so focusing efficiency is not very good.

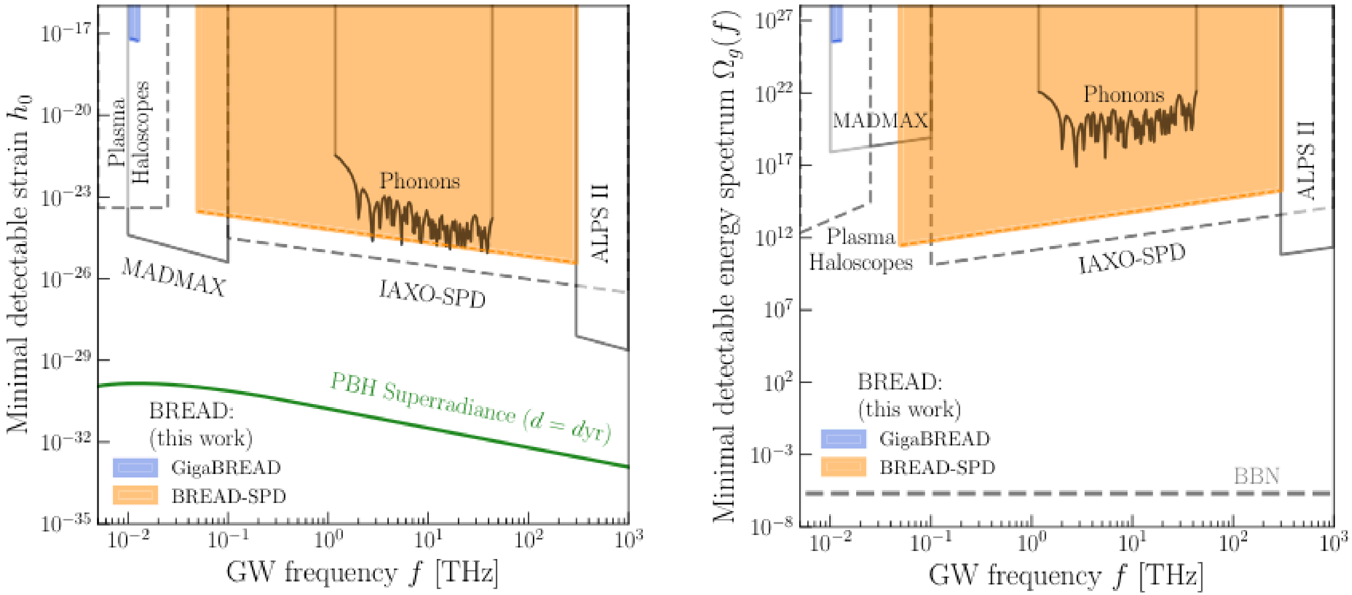




- Some of the lack of focusing efficiency is offset by the fact that the signal is produced over the whole reflector volume.
- In the microwave regime, need to model the coupling to an antenna.

Images from: [26]

Sensitivity Plots



- BREAD has compelling sensitivity to both monochromatic (left) and stochastic (right) gravitational waves.
- In the single-photon regime, BREAD is especially sensitive as it can operate below the SQL [26]

Plot from: [26]

Thanks Everyone!

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