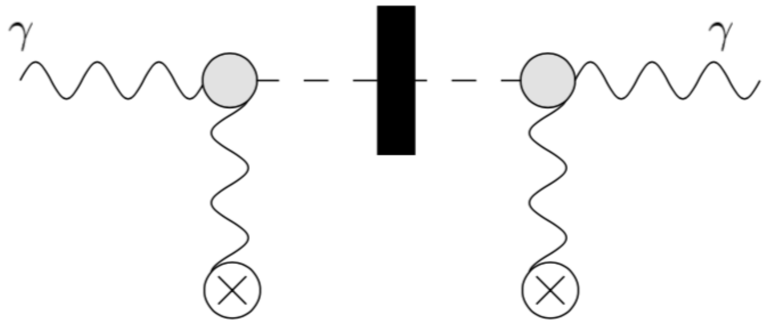
Gravitational Wave Searches @ DESY

Andreas Ringwald
First DMLab Meeting: Scientific Kickoff
ZOOM
09-10 December 2021

Gravitational Wave Searches with ALPS & Co

Light Shining through Walls (LSW)

- **Any-Light-Particle-Search (ALPS)** experiment @ DESY searches for the conversion of photons into light particles and vice versa in a strong transverse magnetic field



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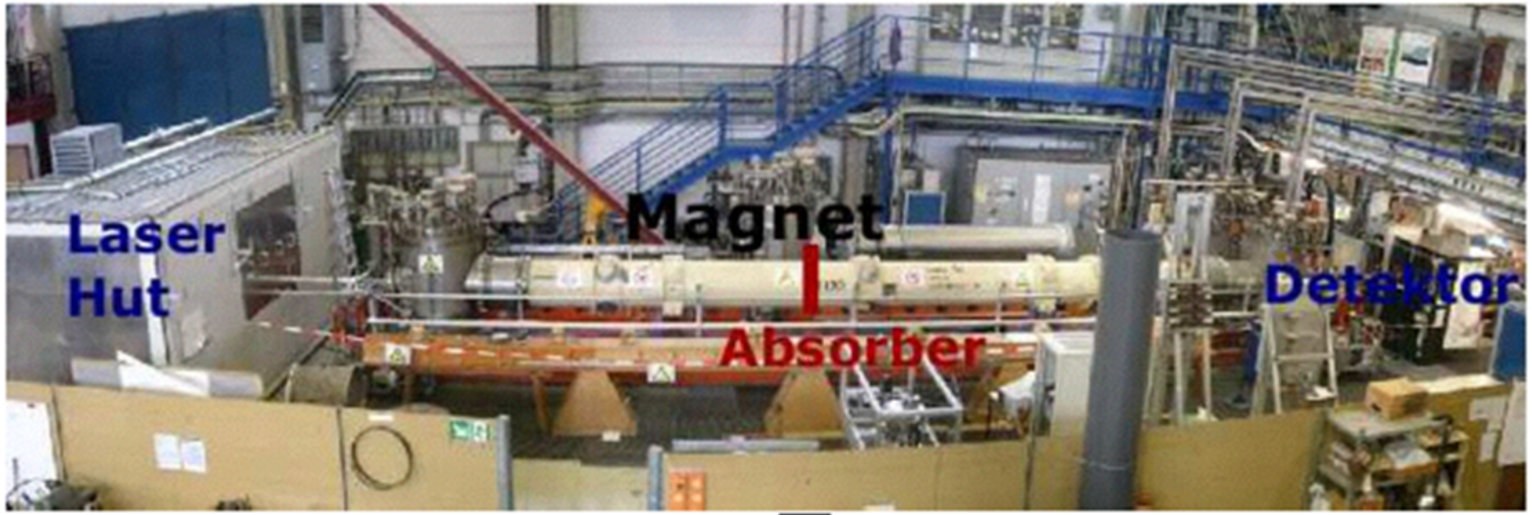

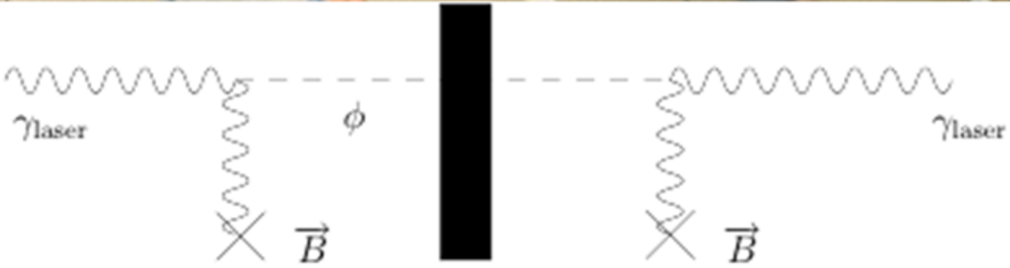

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  - **ALPS I** (data taking 2009):
    - 1 HERA dipole
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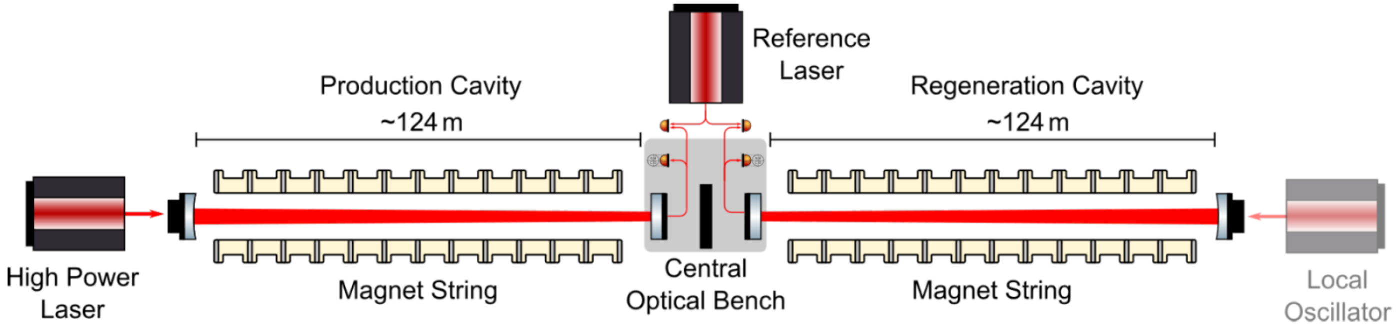
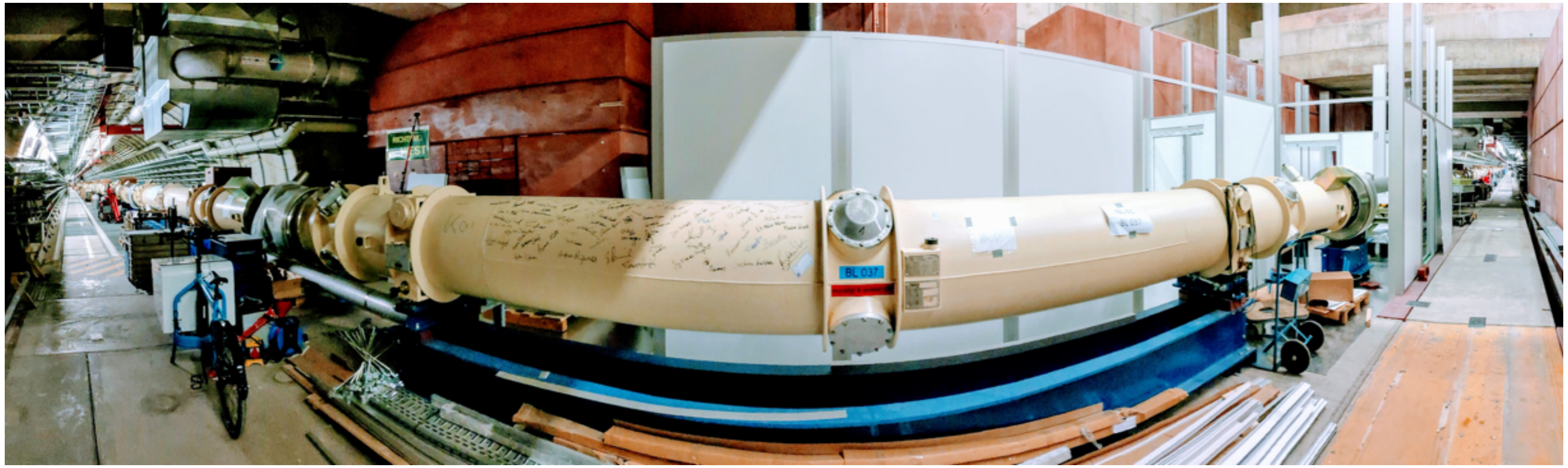
  - **ALPS II** (data taking 2022):
    - 12 + 12 HERA dipoles
    - Additional optical cavity on regeneration side to enhance reconversion





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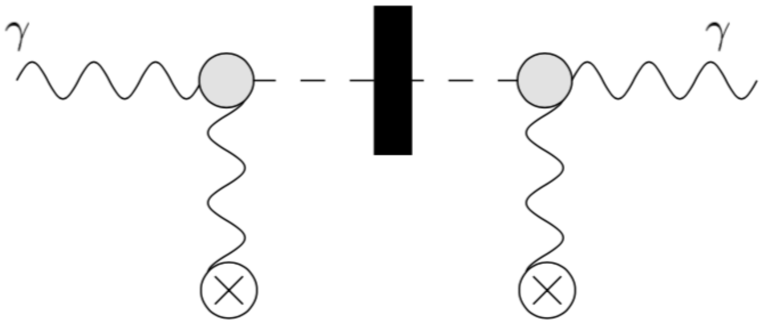

- In the Standard Model (SM), light-shining-through walls (LSW) occurs dominantly through magnetic conversion of gravitons:

$$P(\gamma \to g \to \gamma) \simeq (8\pi G)^2 (BL)^4 \equiv \frac{1}{M_P^4}(BL)^4$$

[Gertsenshtein 1962]

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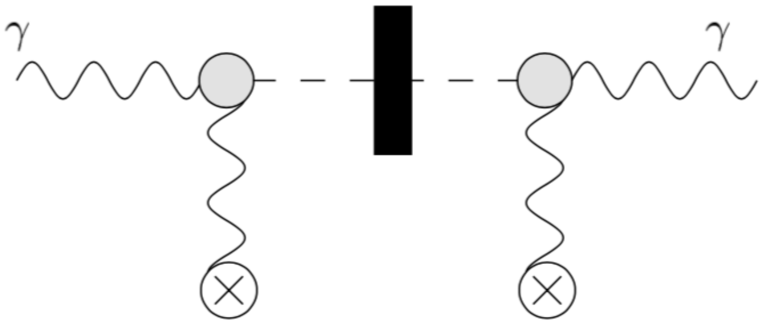

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[Gertsenshtein 1962]

- In a Peccei-Quinn extension of the SM, LSW can also proceed via magnetic conversion of axions or axion-like particles (ALPs):

$$P(\gamma \to a \to \gamma) \simeq \left[\frac{1}{4} g_{a\gamma}^2\right]^2 (BL)^4$$

[Sikivie 1983]

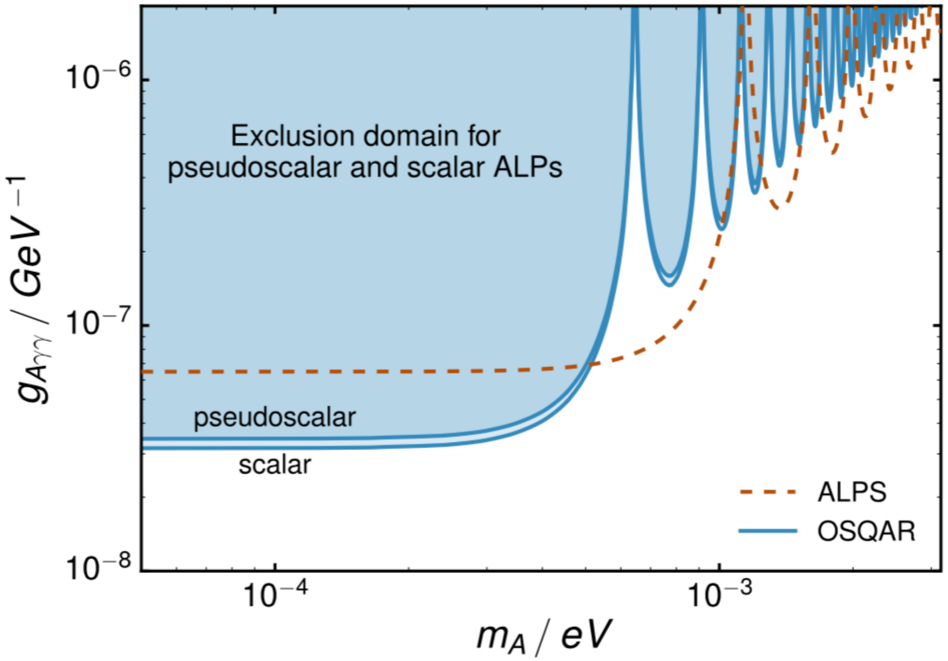
$$\mathcal{L} \supset -\frac{g_{a\gamma}}{4}\, a\, F_{\mu\nu}\tilde{F}^{\mu\nu} \equiv g_{a\gamma}\, a\, \mathbf{E}\cdot\mathbf{B}$$

Gravitational Wave Searches with ALPS & Co

Light Shining through Walls (LSW)

- ALPS I and OSQAR @ CERN give currently best purely laboratory limit on the photon coupling of light ALPs:

[Ehret et al. 10; Ballou et al. 15]



[Ballou et al. 15]

- If interpreted in terms of photon conversion into gravitons and vice versa, this limit can be translated into a lower bound on the Planck mass:

$$M_P \,\widehat{=}\, \frac{2}{g_{a\gamma}} > 7 \times 10^7\,\mathrm{GeV}$$

  - Far away from actual value inferred from measurements of the Newton constant: $M_P \equiv 1/\sqrt{8\pi G} \simeq 2.4 \times 10^{18}\,\mathrm{GeV}$

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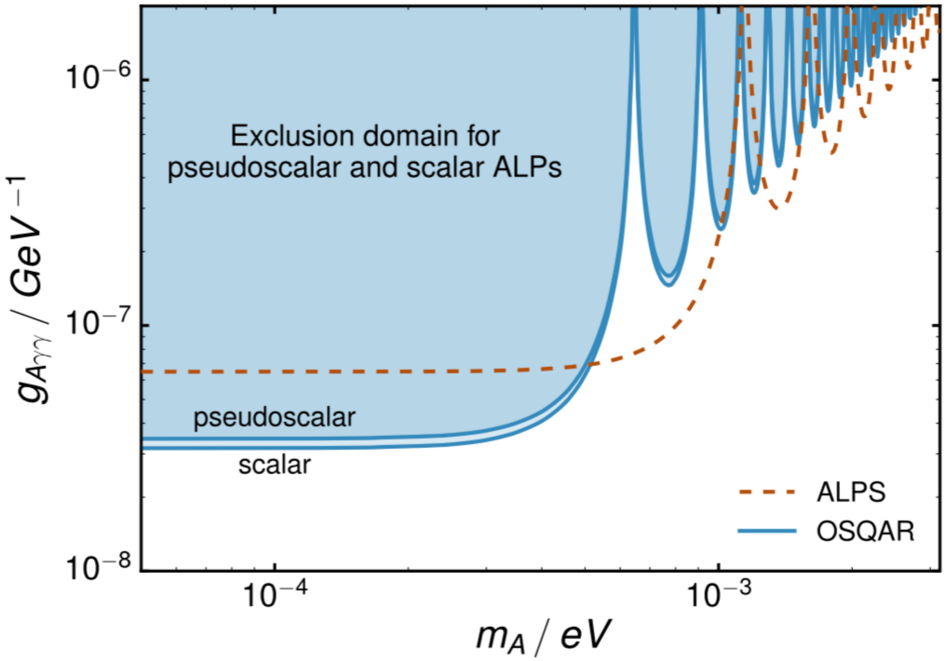

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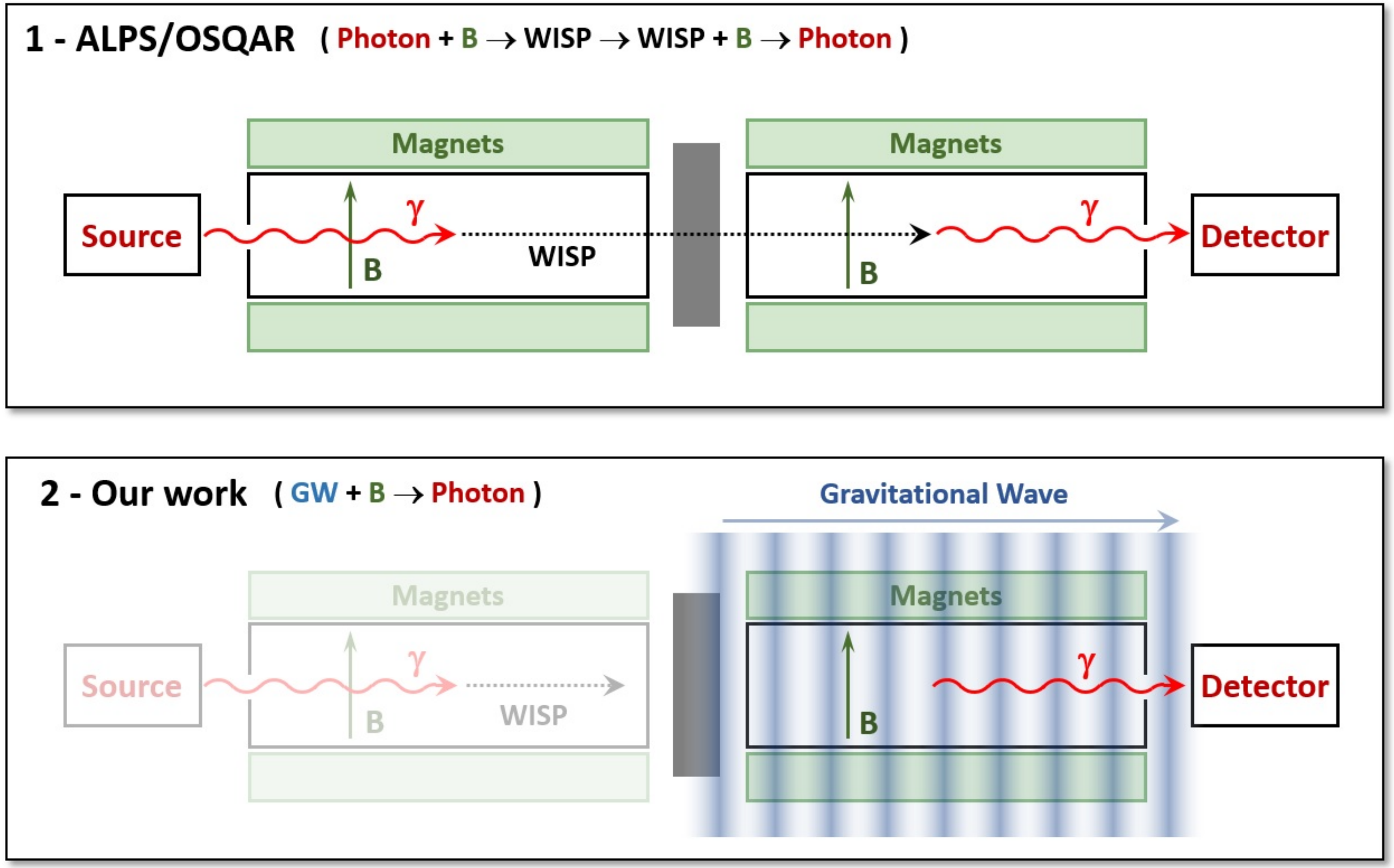
  - ALPS II prospects: $M_P \mathrel{\widehat{=}} \frac{2}{g_{a\gamma}} > 10^{11}\,\mathrm{GeV}$

Gravitational Wave Searches with ALPS & Co

Upper limits on stochastic GW background from LSW experiments and helioscopes

- LSW experiments (ALPS, OSQAR) and helioscopes (CAST, (Baby)IAXO are sensitive to any stochastic GW background due to graviton photon conversion:

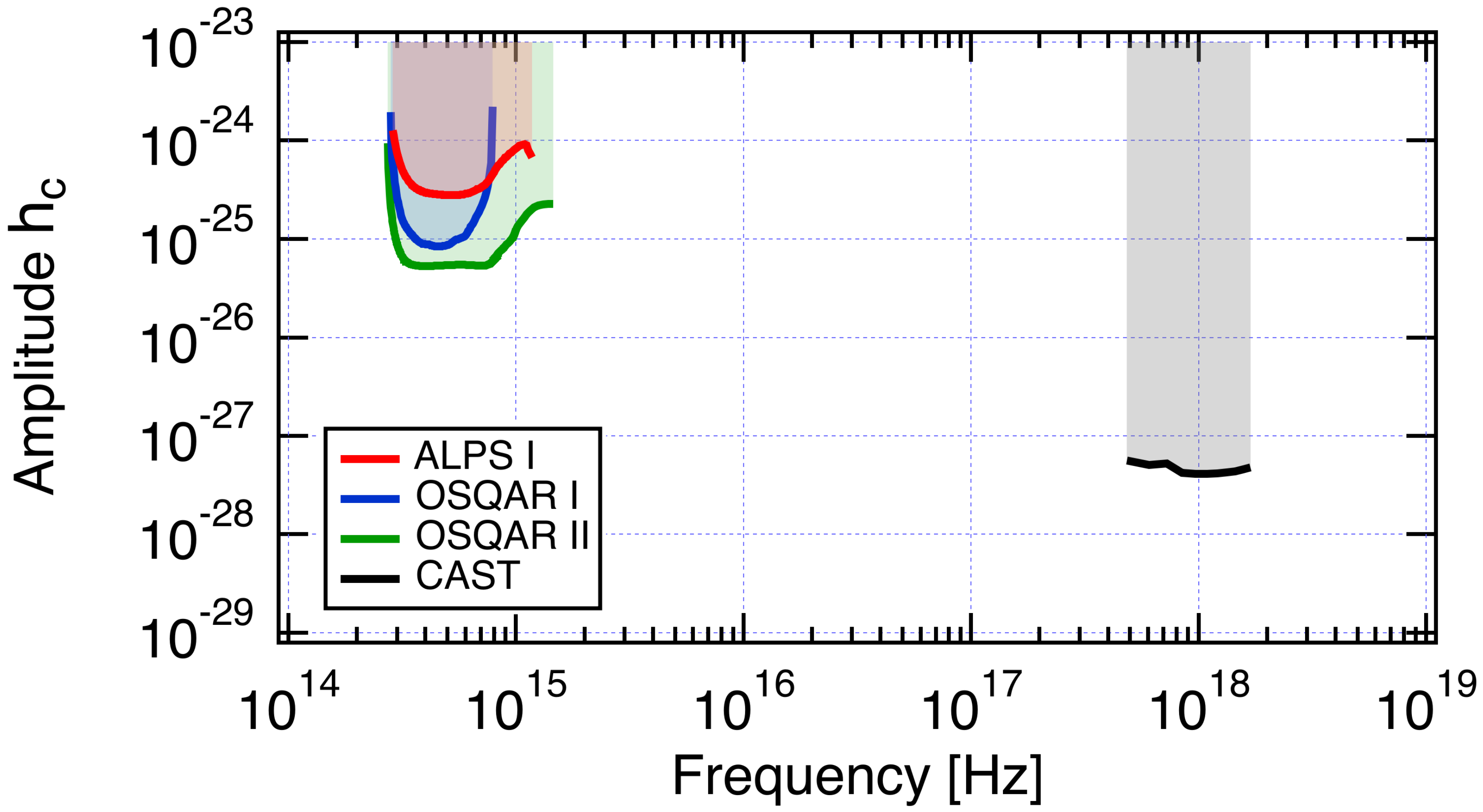


[Ejlli et al 2019]

Gravitational Wave Searches with ALPS & Co

Upper limits on stochastic GW background from LSW experiments and helioscopes

- Bounds on the axion photon coupling obtained by ALPS, OSQAR, CAST can be translated into bounds on the characteristic amplitude of the stochastic GW background:



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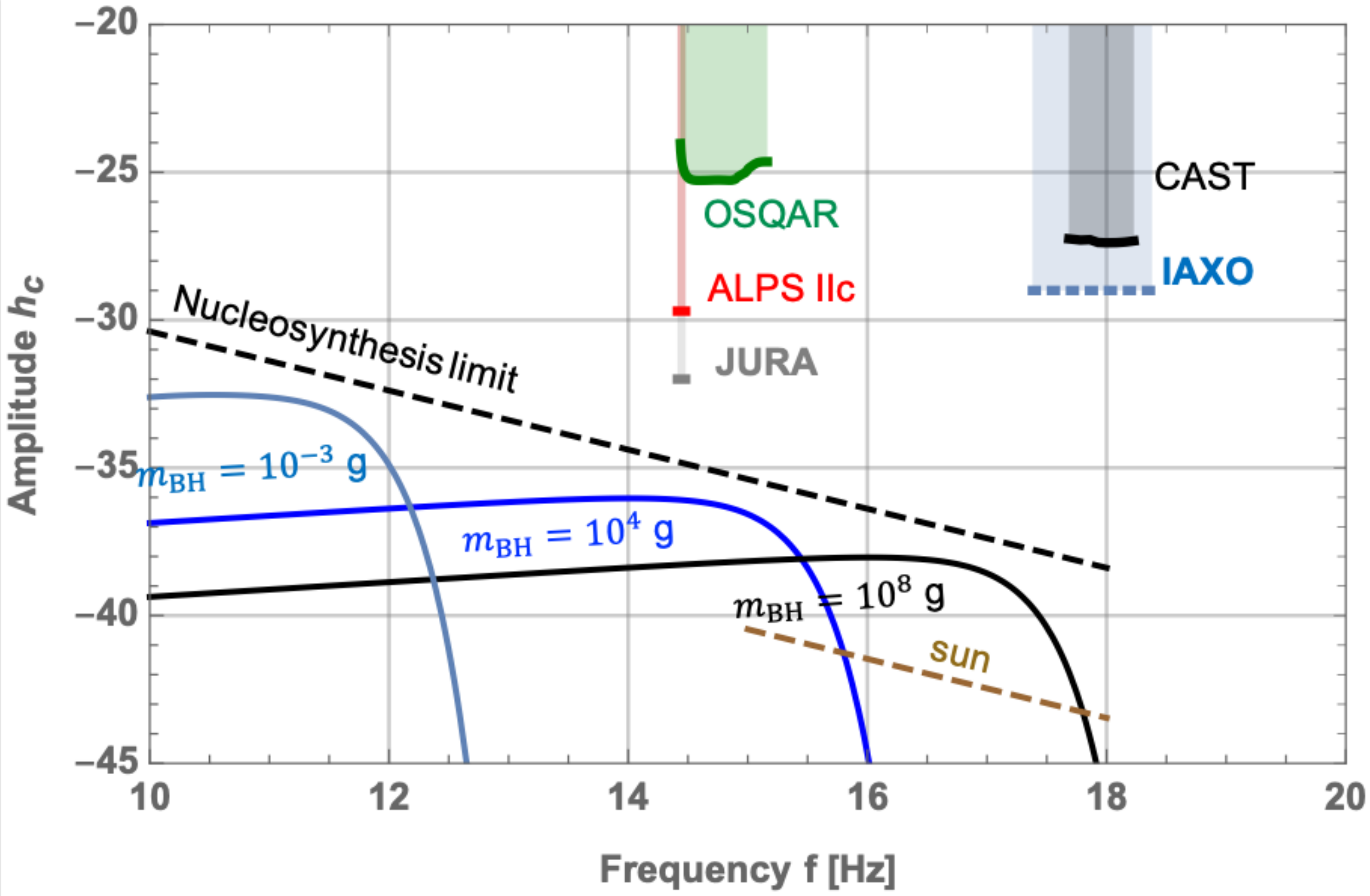
Upper limits on stochastic GW background from LSW experiments and helioscopes

- Projected bounds from LSW experiments and helioscopes:

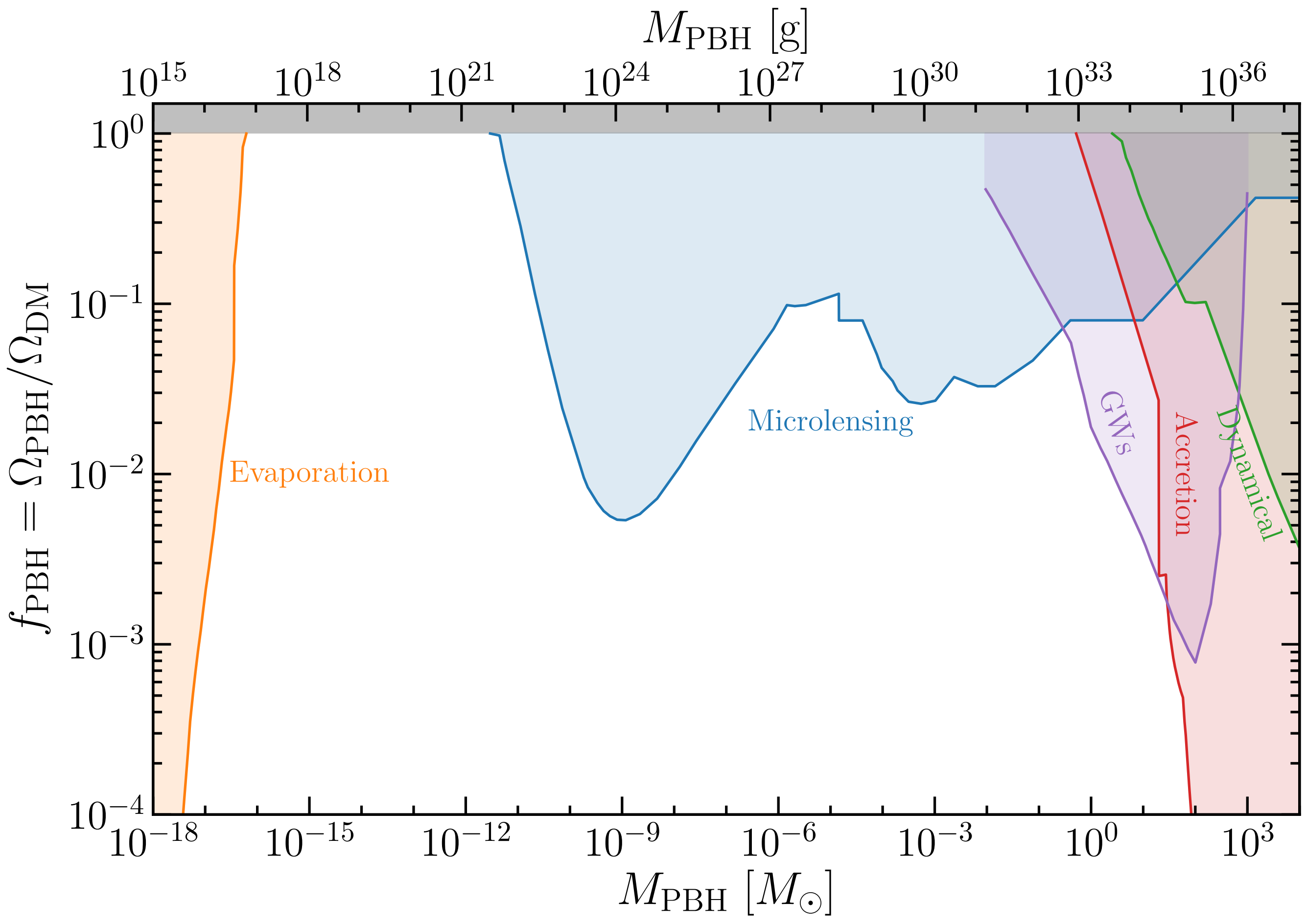


[Ejlli et al 2019]

Stochastic GW Background from Primordial Black Holes

Primordial black holes as dark matter candidates

- Primordial black holes (PBHs) are formed in early universe by collapse of large density fluctuations generated during inflation
- PBHs with masses
  - below 10^{15} g would have evaporated by now by means of Hawking radiation
  - in the asteroid range (10^{17} g < m_{PBH} <10^{22} g) may constitute all of dark matter (DM)
  - in the planetary to multi-Solar mass range can only make up a subdominant fraction of DM



Green and Kavanagh 2020, https://inspirehep.net/literature/1808121

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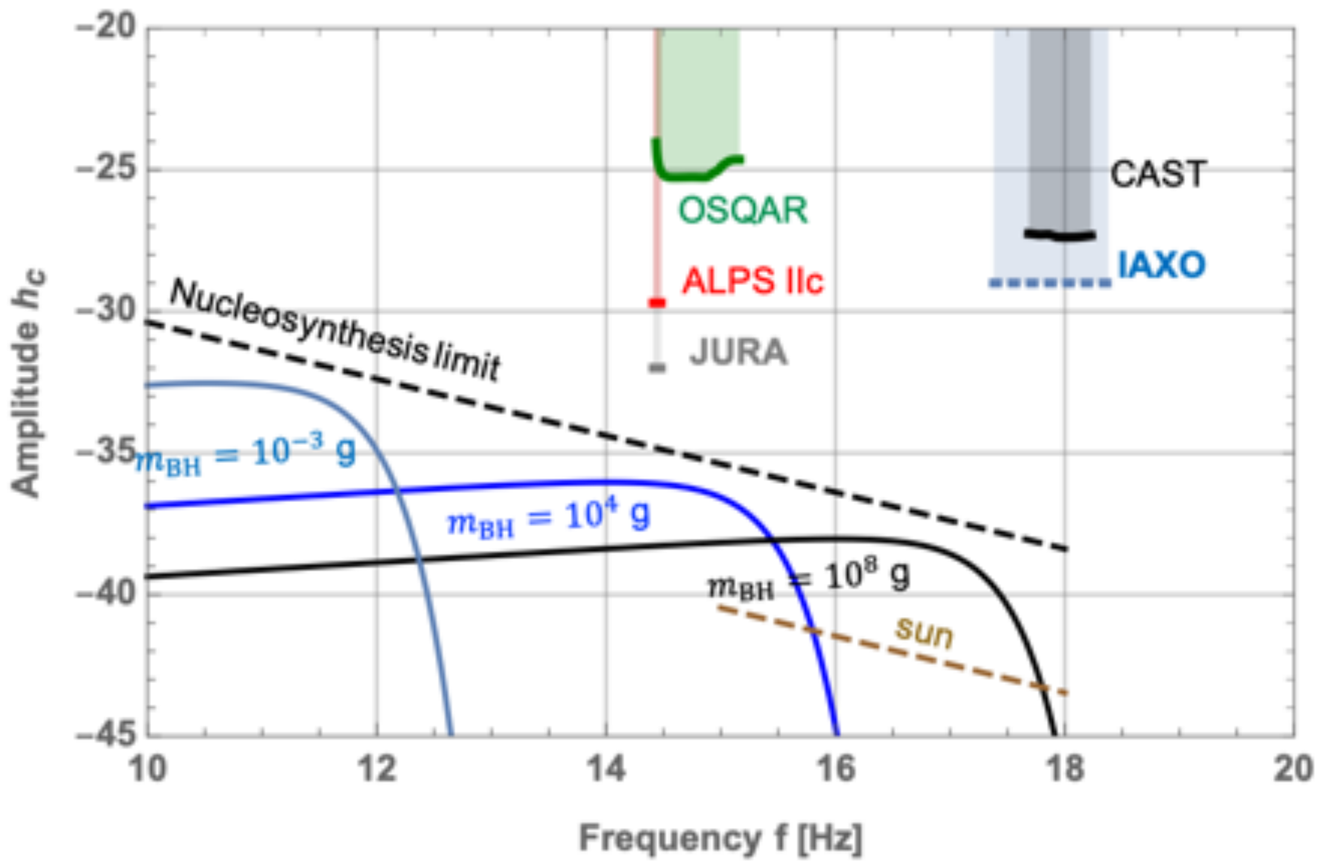
    - Peak in ALPS II frequency range for m_{PBH}~10^4 g



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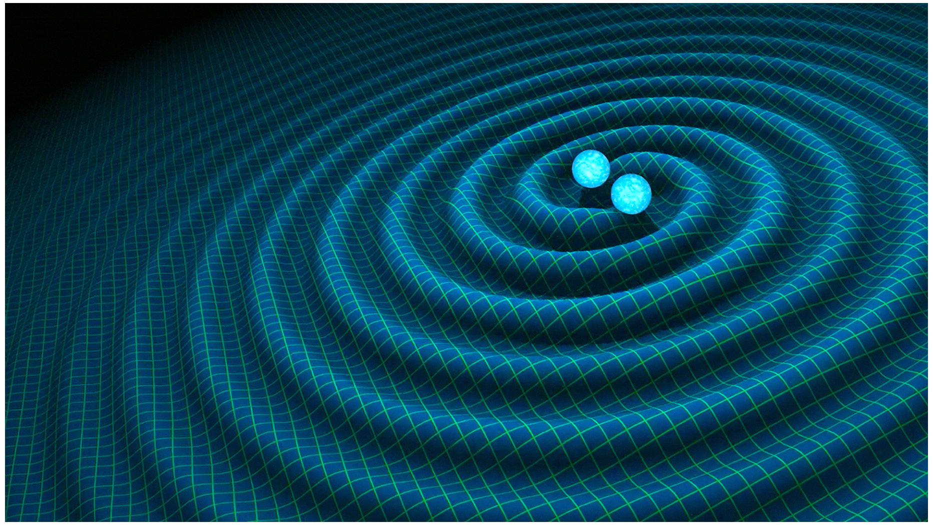

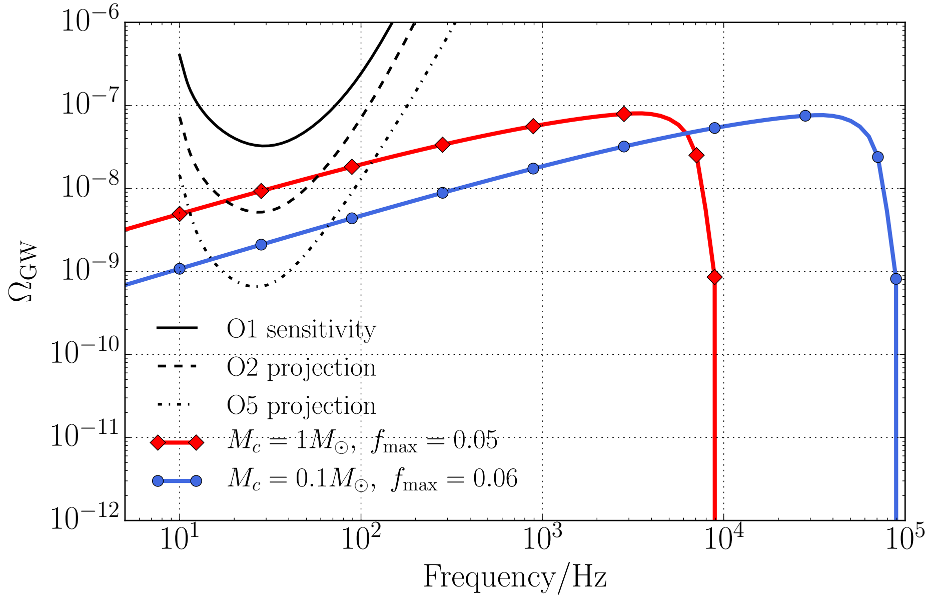

Wang et al. https://inspirehep.net/literature/1494768

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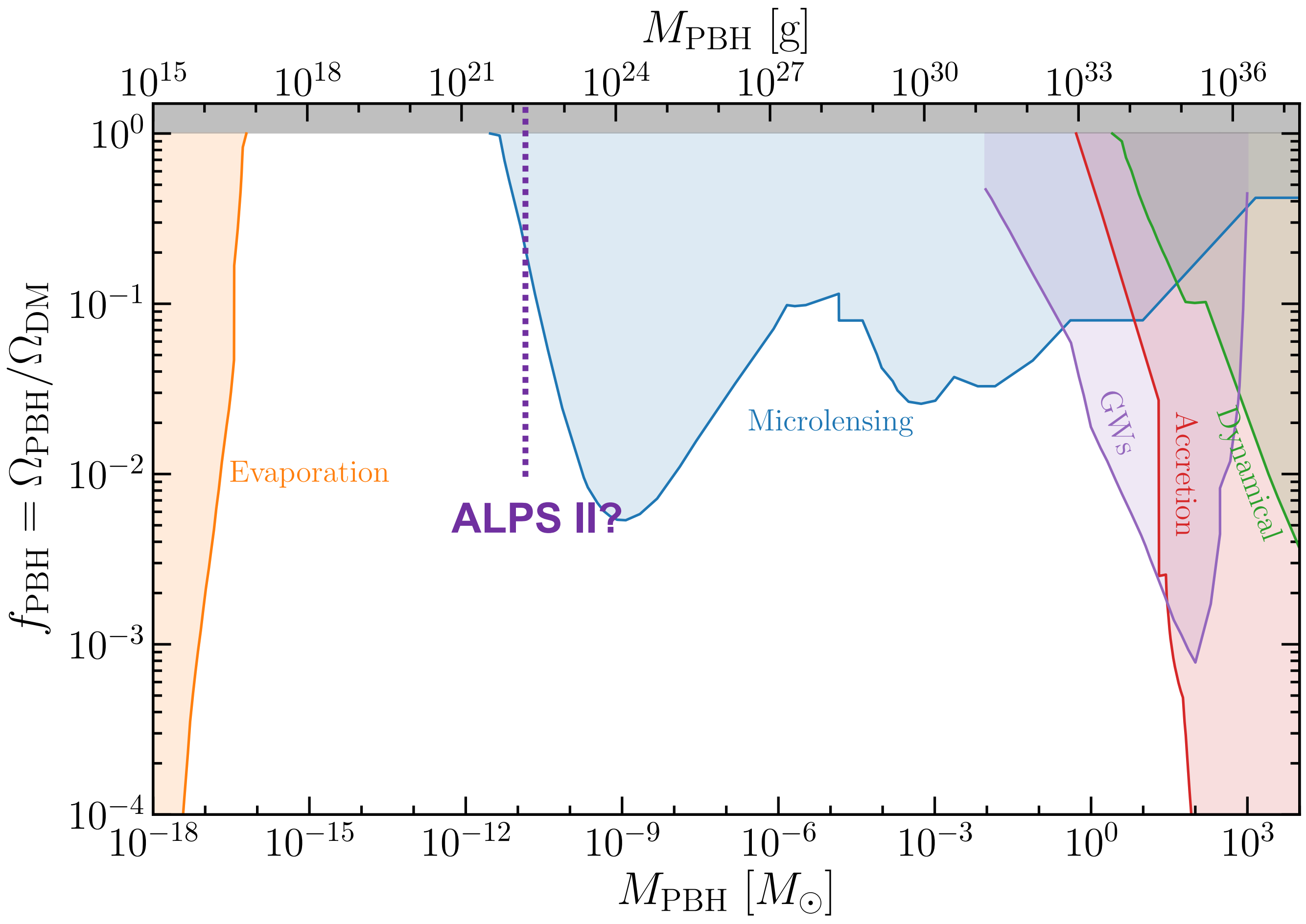

[Ballesteros, Garcia Cely, AR in progress]

GW Detection Opportunities beyond ALPS & Co?

- Currently, a community is forming which seriously considers the search for high-frequency gravitational waves:

CERN-TH-2020-185
HIP-2020-28/TH
DESY 20-195

arXiv:2011.12414v1 [gr-qc] 24 Nov 2020

Challenges and Opportunities of Gravitational Wave Searches at MHz to GHz Frequencies

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Abstract

The first direct measurement of gravitational waves by the LIGO and Virgo collaborations has opened up new avenues to explore our Universe. This white paper outlines the challenges and gains expected in gravitational wave searches at frequencies above the LIGO/Virgo band, with a particular focus on the MHz and GHz range. The absence of known astrophysical sources in this frequency range provides a unique opportunity to discover physics beyond the Standard Model operating both in the early and late Universe, and we highlight some of the most promising gravitational sources. We review several detector concepts which have been proposed to take up this challenge, and compare their expected sensitivity with the signal strength predicted in various models. This report is the summary of the workshop *Challenges and opportunities of high-frequency gravitational wave detection* held at ICTP Trieste, Italy in October 2019.

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[γ] *Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan.*

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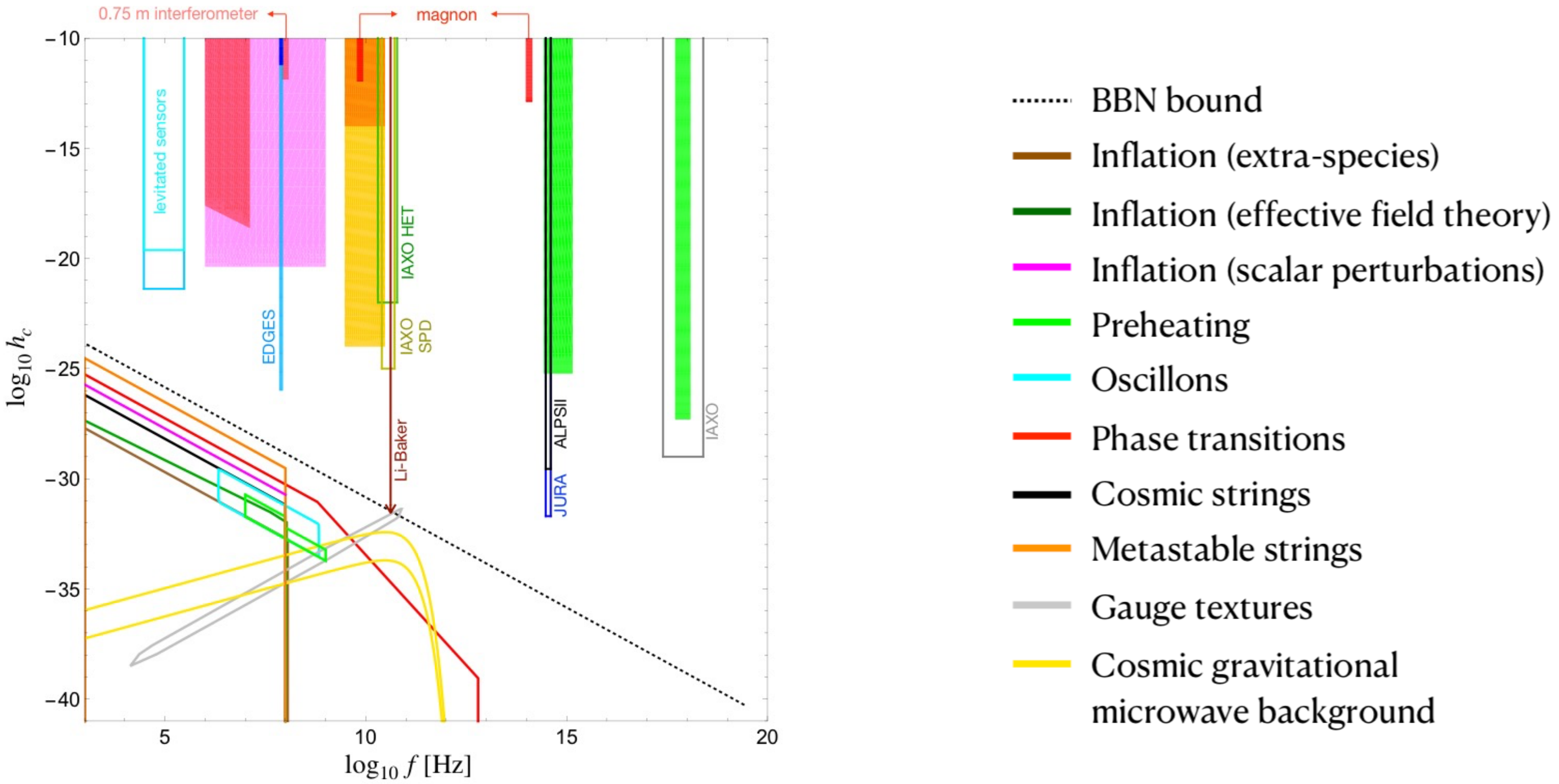

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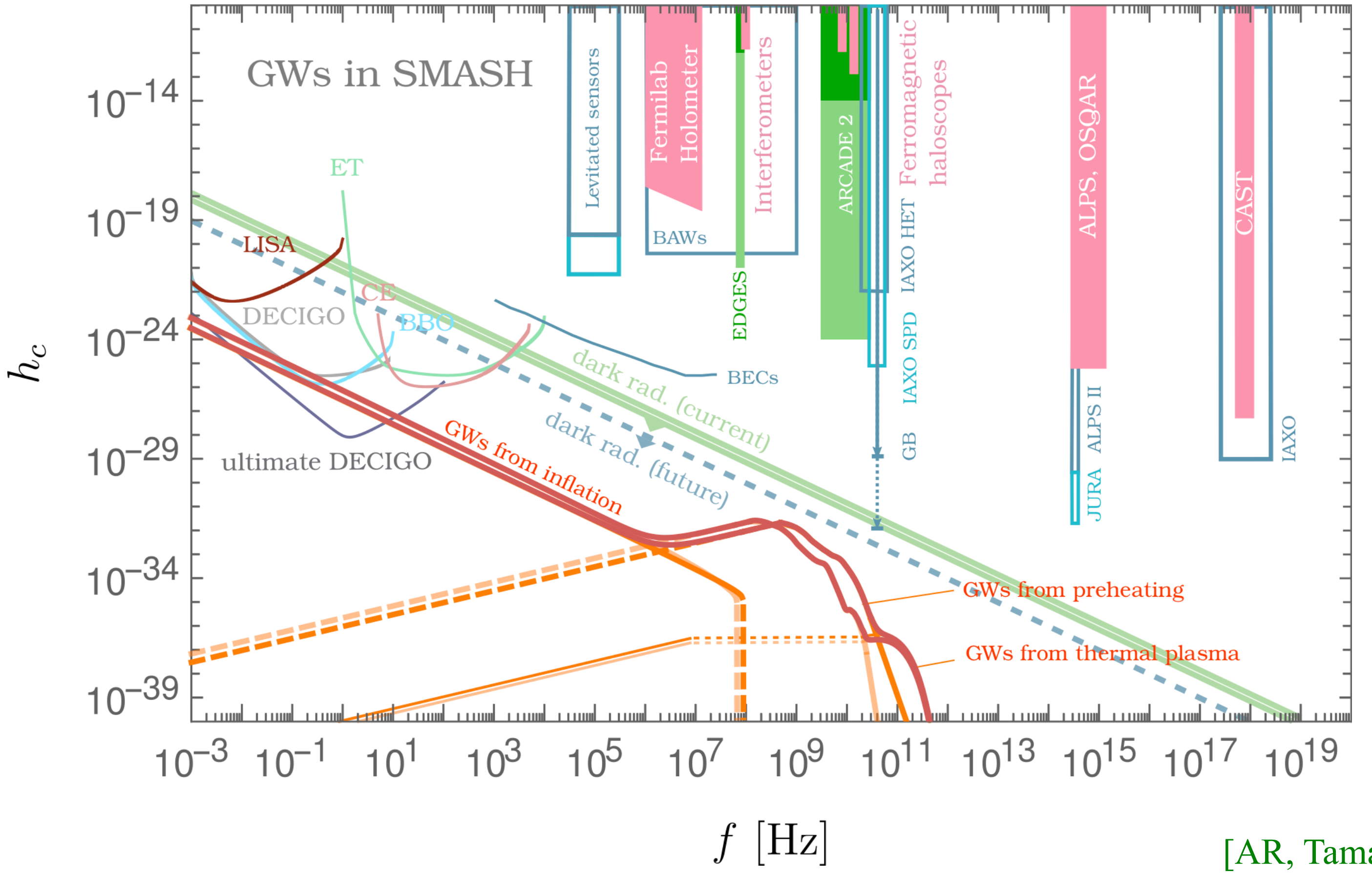

[AR, Tamarit in progress]

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