

A novel search for gravitational waves inspired by axion dark matter

**Latin American Symposium on High Energy Physics
(SILAFEA)**

Quito, Ecuador
November 17, 2022

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Ramón y Cajal Researcher



Novel Search for High-Frequency Gravitational Waves with Low-Mass Axion Haloscopes

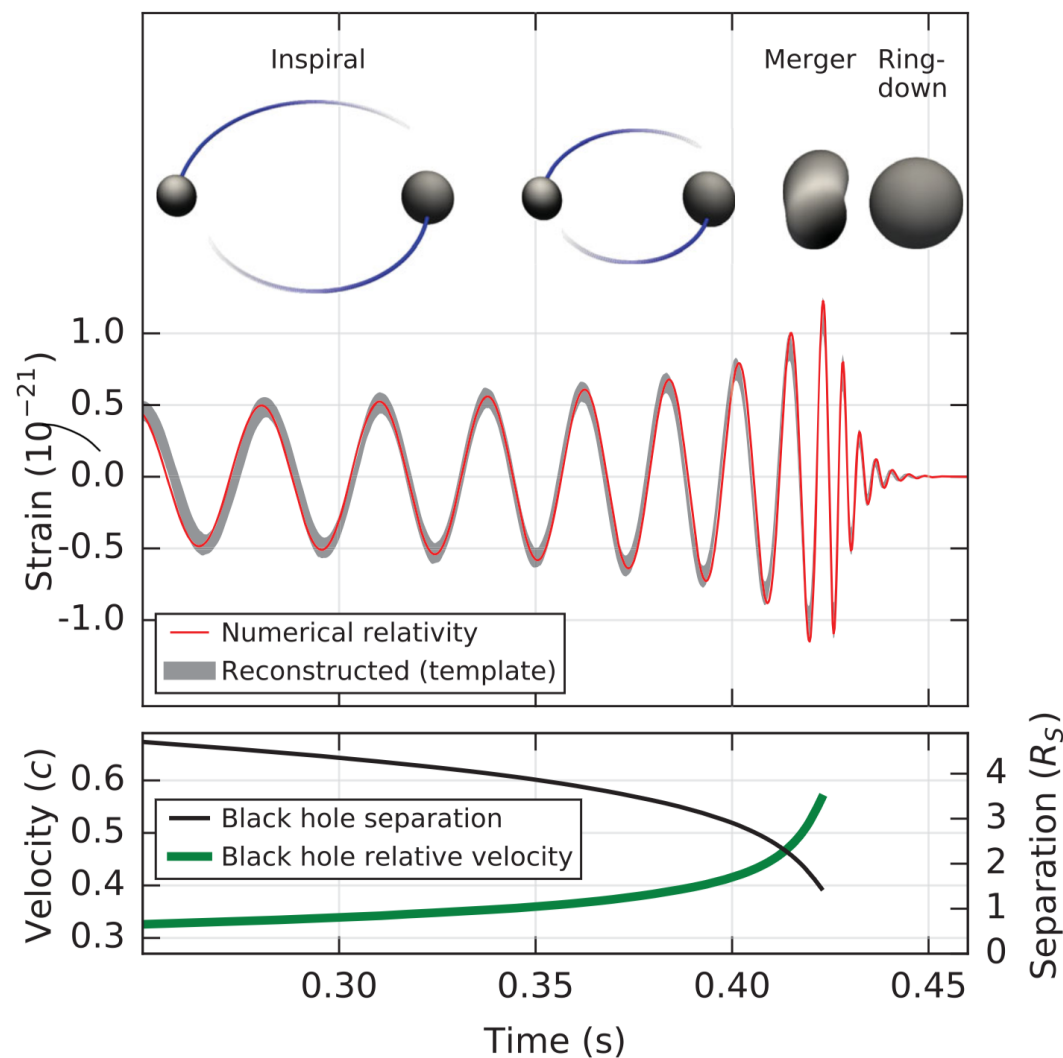
Valerie Domcke, Camilo Garcia-Cely, and Nicholas L. Rodd
Phys. Rev. Lett. **129**, 041101 – Published 20 July 2022

Outline

- Motivation
- Adapting axion experiments to detect gravitational waves
- Conclusions

Motivation

Gravitational waves from black holes



PRL 116, 061102 (2016)

PHYSICAL REVIEW LETTERS

12 FEBRUARY 2016

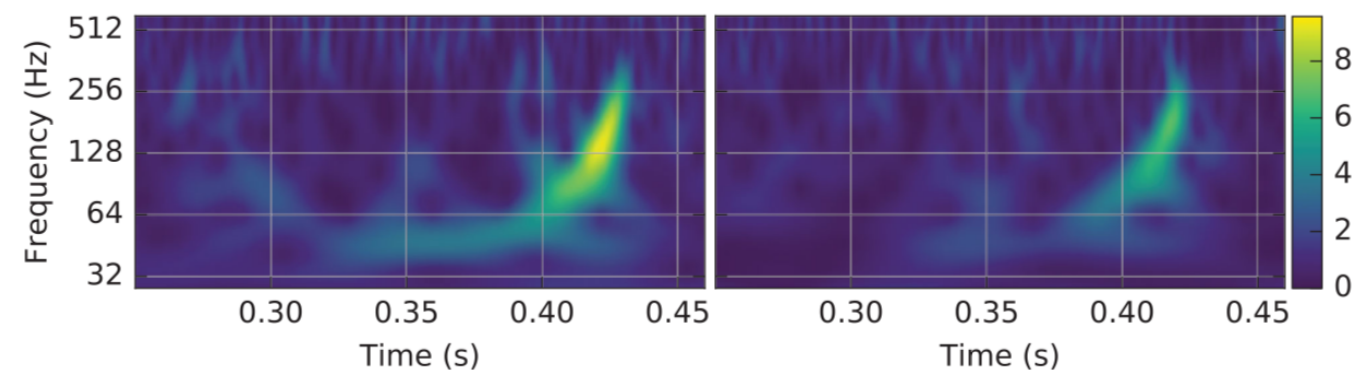


Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)



$$f \approx 2.2 \text{ kHz} \left(\frac{M_{\odot}}{m_{\text{BH}}} \right)$$

Subsolar primordial black holes can produce high frequency GWs

High-frequency gravitational waves

No known astrophysical objects are small and dense enough to produce gravitational waves beyond 10 kHz

Part of a collection:

[Gravitational Waves](#)

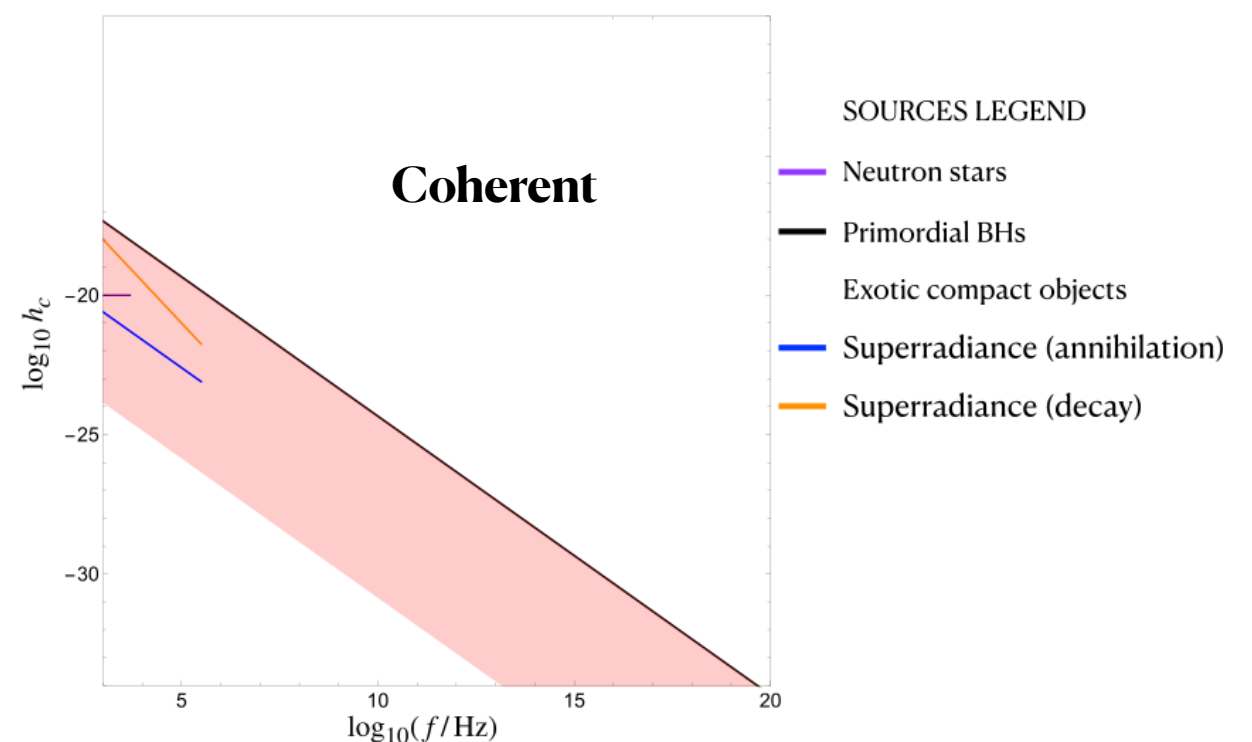
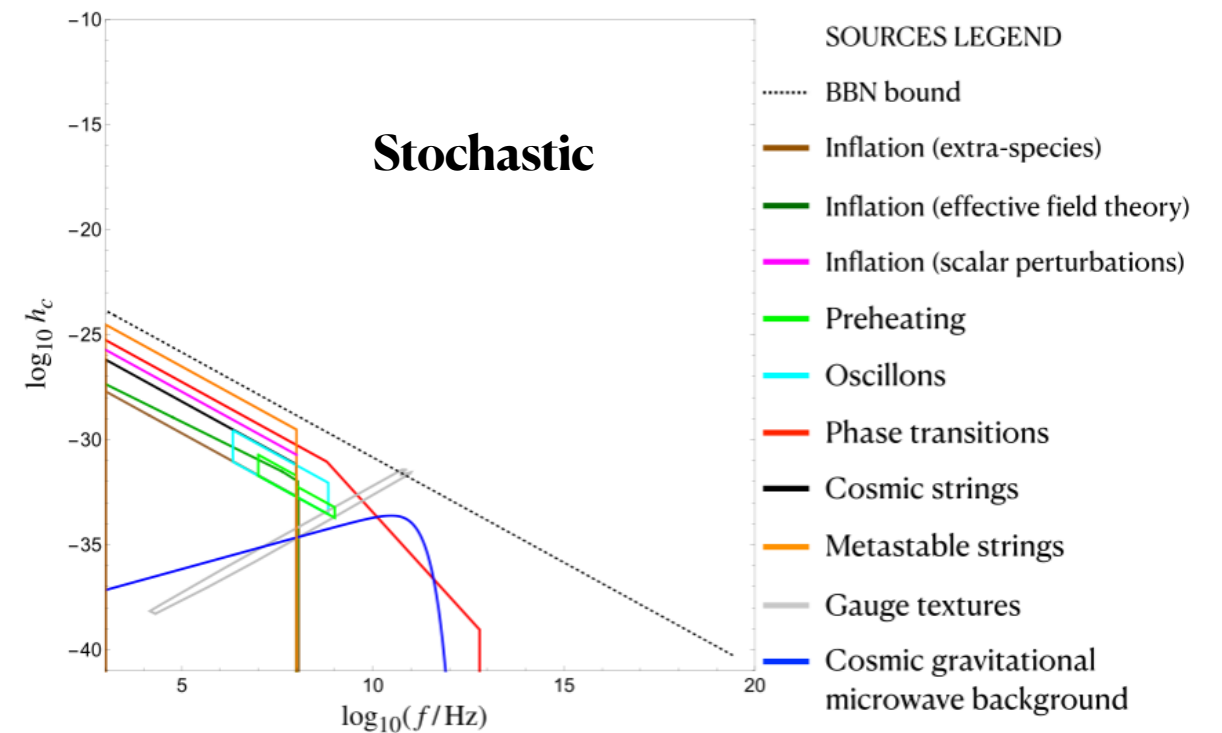
Review Article | [Open Access](#) | [Published: 06 December 2021](#)

Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies

[Nancy Aggarwal](#) , [Odylio D. Aguiar](#), [Andreas Bauswein](#), [Giancarlo Cella](#), [Sebastian Clesse](#), [Adrian Michael Cruise](#), [Valerie Domcke](#) , [Daniel G. Figueroa](#), [Andrew Geraci](#), [Maxim Goryachev](#), [Hartmut Grote](#), [Mark Hindmarsh](#), [Francesco Muia](#) , [Nikhil Mukund](#), [David Ottaway](#), [Marco Peloso](#), [Fernando Quevedo](#) , [Angelo Ricciardone](#), [Jessica Steinlechner](#) , [Sebastian Steinlechner](#) , [Sichun Sun](#), [Michael E. Tobar](#), [Francisco Torrenti](#), [Caner Ünal](#) & [Graham White](#)

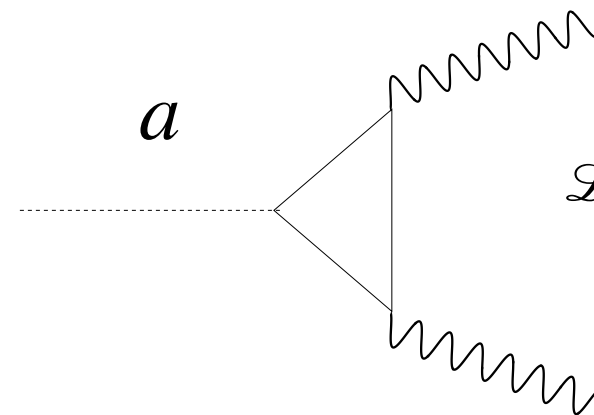
[Living Reviews in Relativity](#) **24**, Article number: 4 (2021) | [Cite this article](#)

A growing community is seriously considering the search of high frequency gravitational waves



Axion dark matter

- Pseudoscalar field



A Feynman diagram illustrating the interaction of an axion field a with two photons. A dashed line labeled a enters from the left and splits into two wavy lines representing photons. To the right of the diagram is the Lagrangian term:

$$\mathcal{L} = -\frac{1}{4}g_{a\gamma\gamma}aF_{\mu\nu}\tilde{F}^{\mu\nu}$$

- Solution to the strong CP problem

Peccei, Quinn 1977

- Excellent dark matter candidate

Weinberg, Wilczek 1978

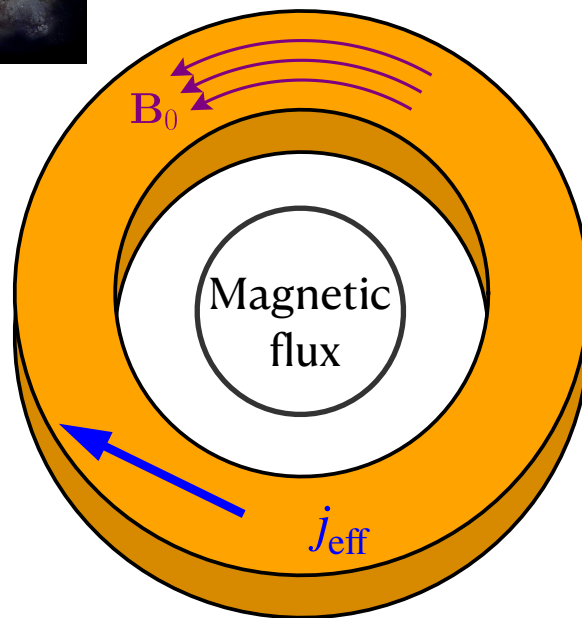
Effective current for axions

Axions act as a source term to Maxwell's equations, **effectively inducing an electromagnetic current.**

$$\begin{aligned}\nabla \cdot \mathbf{B} &= 0 && \text{Sikivie, 1983} \\ \nabla \times \mathbf{E} + \partial_t \mathbf{B} &= 0 \\ \nabla \cdot \mathbf{E} &= j^0 \\ \nabla \times \mathbf{B} - \partial_t \mathbf{E} &= \mathbf{j}\end{aligned}$$

$$j^0 = -g_{a\gamma\gamma} \nabla a \cdot \mathbf{B} \quad \mathbf{j} = g_{a\gamma\gamma} \left(\nabla a \times \mathbf{E} + \partial_t a \mathbf{B} \right)$$

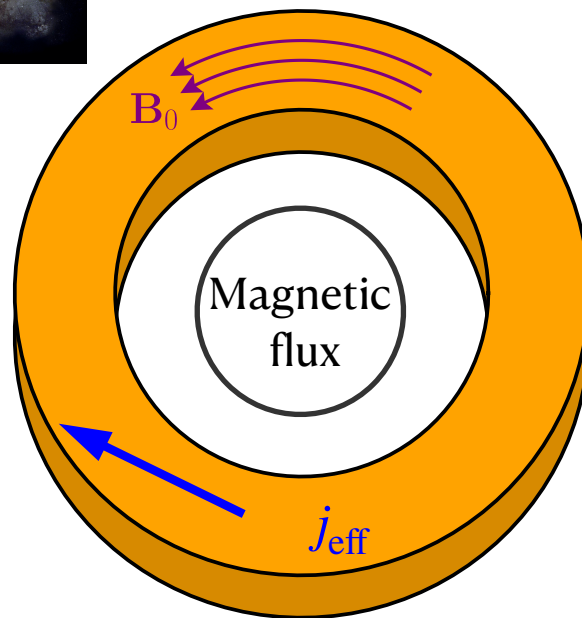
Low mass axion haloscopes



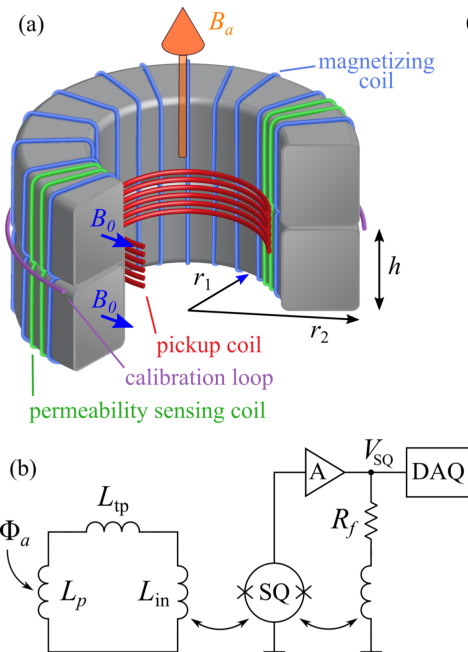
$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = \underbrace{g_{a\gamma\gamma} \partial_t a}_{j_{\text{eff}}} \mathbf{B}_0$$

The electromagnetic fields produced by the axion drive a current through a pickup coil

Low mass axion haloscopes



$$\nabla \times \mathbf{B} - \underbrace{\partial_t \mathbf{E}}_{j_{\text{eff}}} = g_{a\gamma\gamma} \partial_t a \mathbf{B}_0$$



(c) SHAFT



physics <https://doi.org/>

Search for axion-like dark matter with ferromagnets

Alexander V. Gramolin¹, Deniz Aybas^{1,2}, Dorian Johnson¹, Janos Adam¹ and Alexander O. Sushkov^{1,2,3}

PRL 117, 141801 (2016)

PHYSICAL REVIEW LETTERS

week ending
30 SEPTEMBER 2016

Broadband and Resonant Approaches to Axion Dark Matter Detection

Yonatan Kahn,^{1,*} Benjamin R. Safdi,^{2,†} and Jesse Thaler^{2,‡}

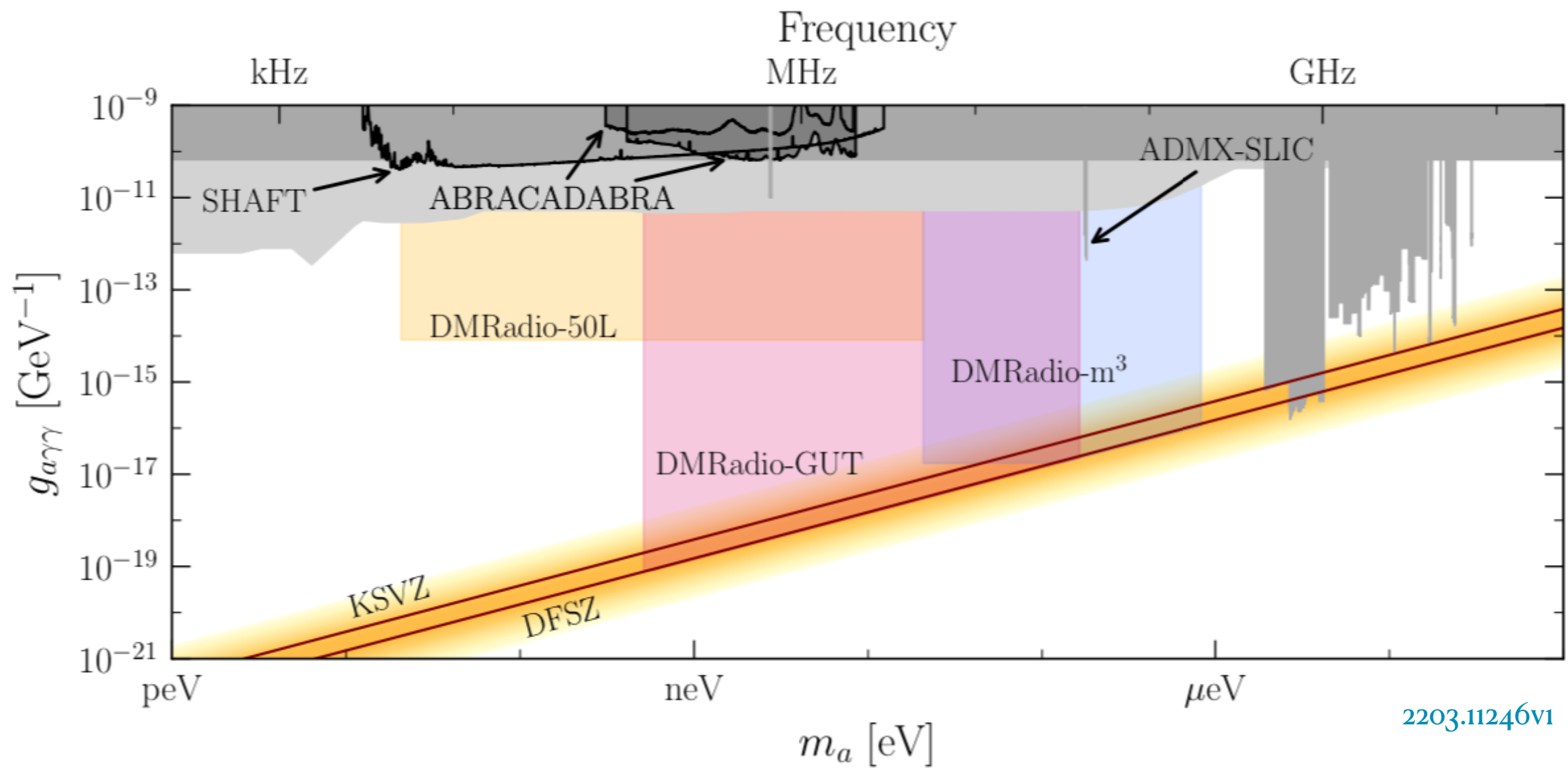
¹Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

²Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

(Received 3 March 2016; published 30 September 2016)

The electromagnetic fields produced by the axion drive a current through a pickup coil

DMRadio program

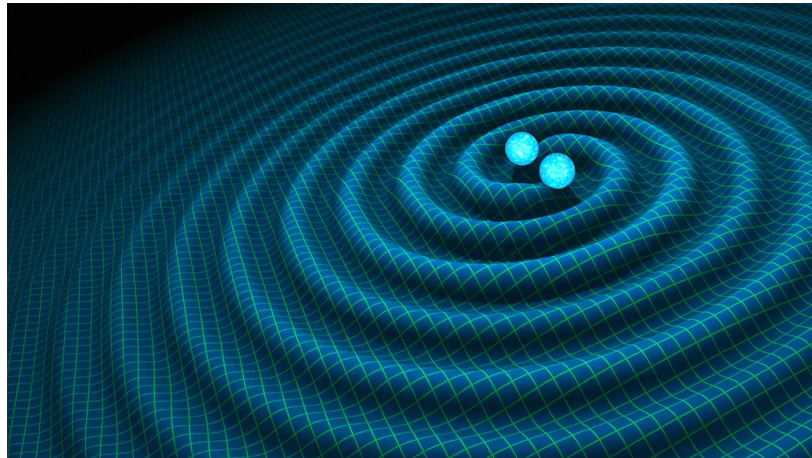


Adapting axion experiments to detect gravitational waves

Effective current for gravitational waves

GWs act as a source term to Maxwell's equations, **effectively inducing an electromagnetic current.**

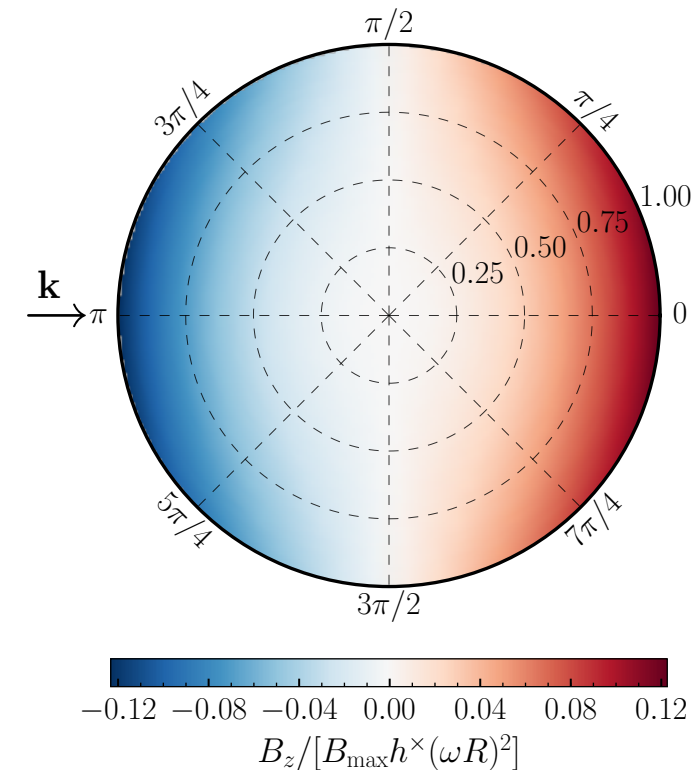
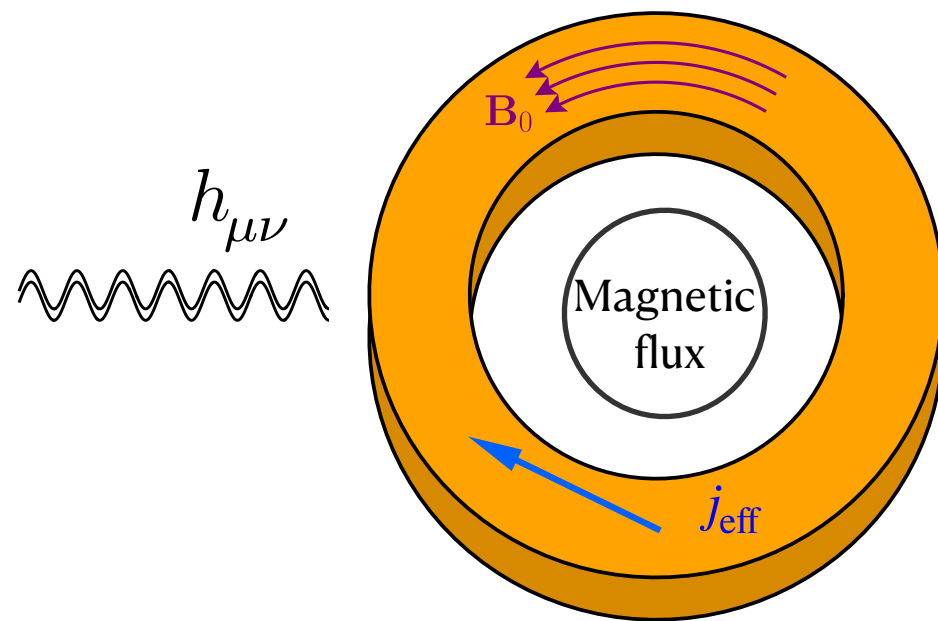
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \quad |h_{\mu\nu}| \ll 1$$



$$j_{\text{eff}}^{\mu} = \partial_{\nu} \left(-\frac{1}{2} h F^{\mu\nu} + F^{\mu\alpha} h^{\nu}_{\alpha} - F^{\nu\alpha} h^{\mu}_{\alpha} \right)$$

Gravitational waves in haloscopes

Domcke, CGC, Rodd, 2202.00695



$$\Phi \approx \frac{ie^{-i\omega t}}{16\sqrt{2}} h^{\times} \omega^3 B_{\max} \pi r^2 R a (a + 2R) s_{\theta_h}^2$$

$$\Phi_{\text{axions}} \approx e^{-i\omega t} g_{a\gamma\gamma} \sqrt{2\rho_{\text{DM}}} B_{\max} \pi r^2 R$$

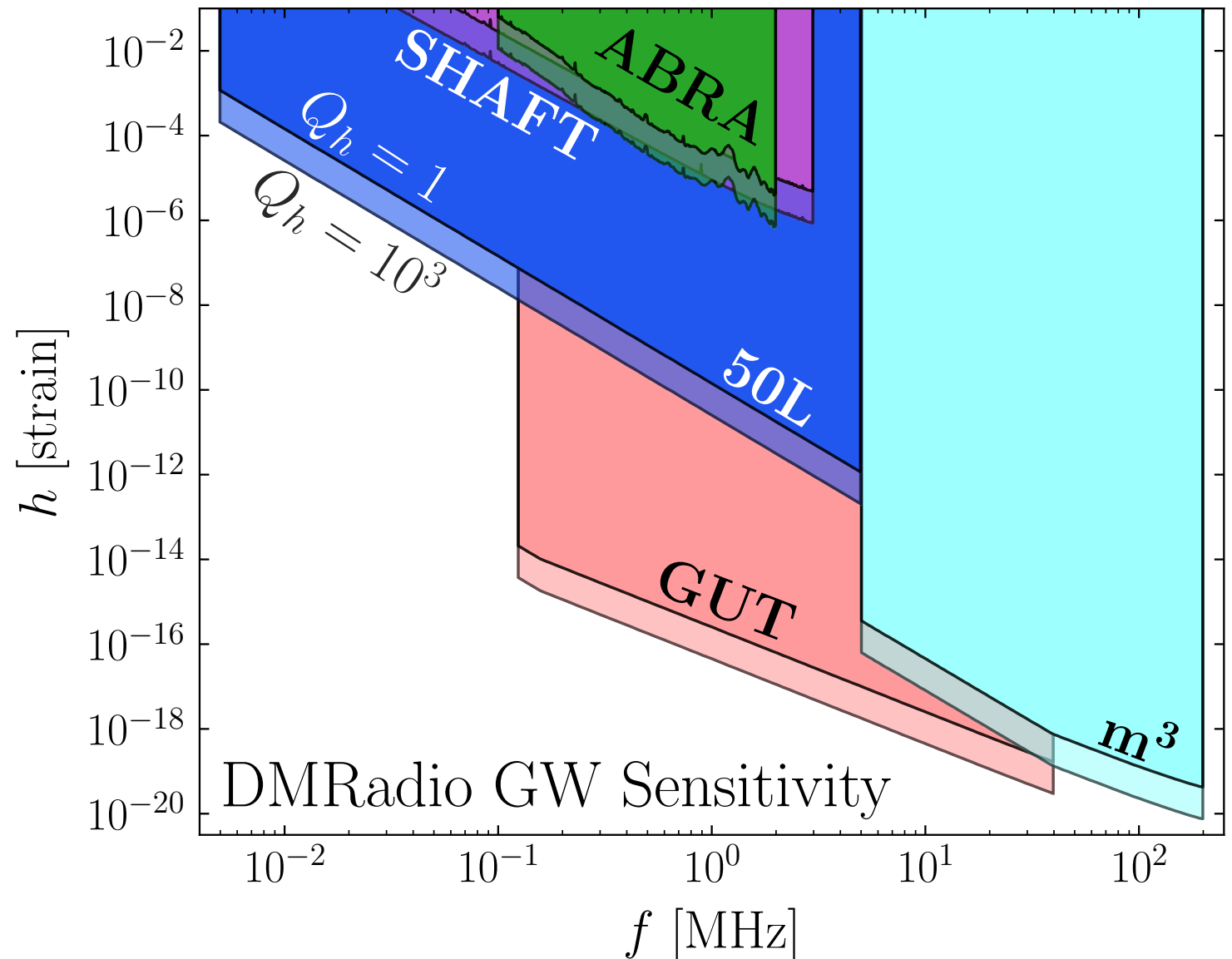
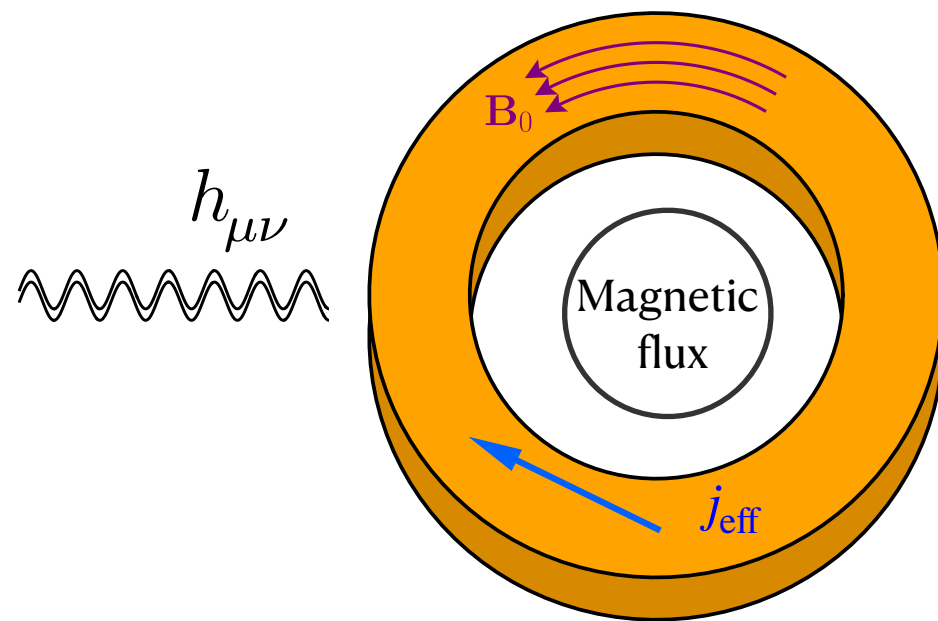
Only one polarization

Suppression at small frequencies

The sensitivity scaling with the volume is faster than for axions

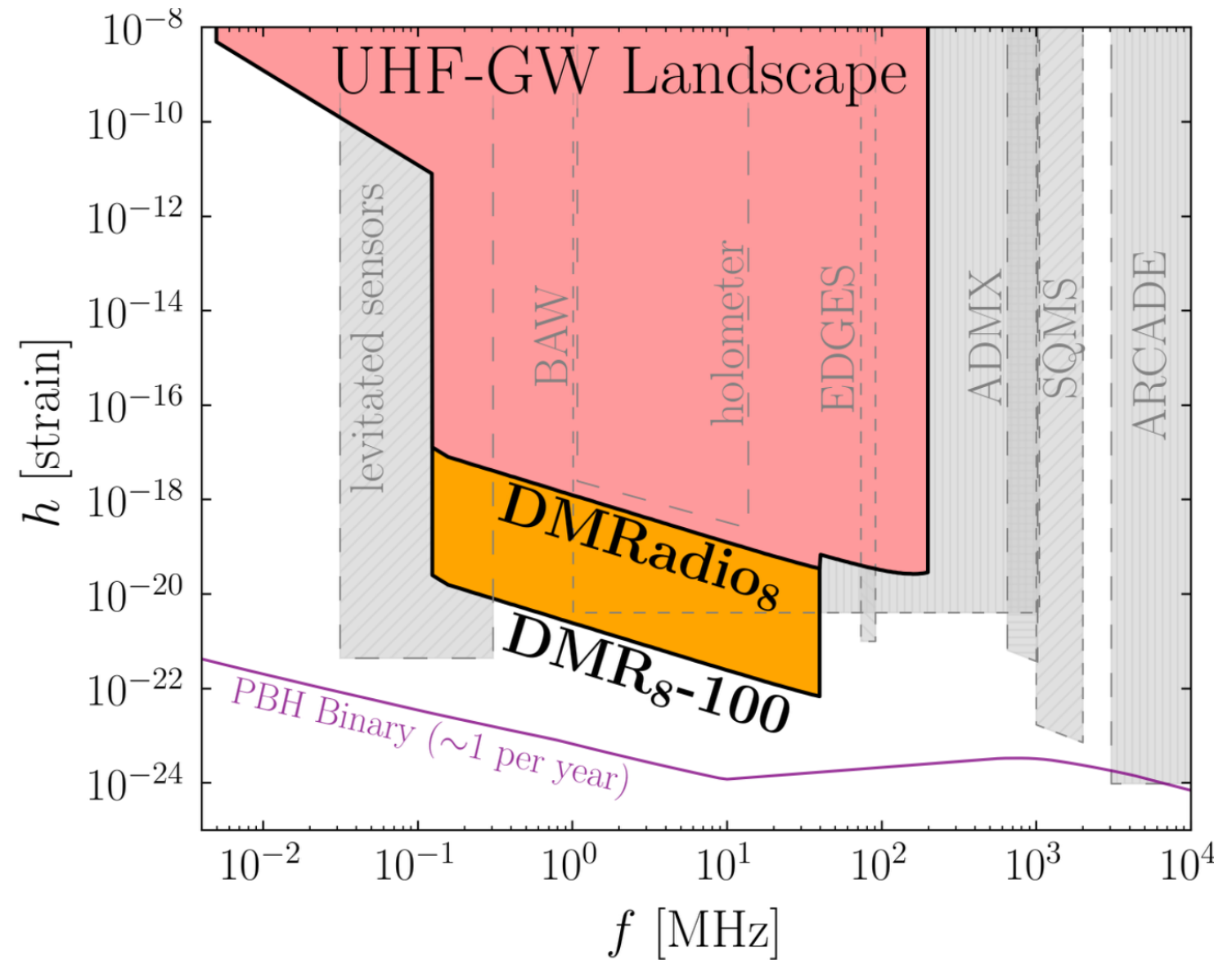
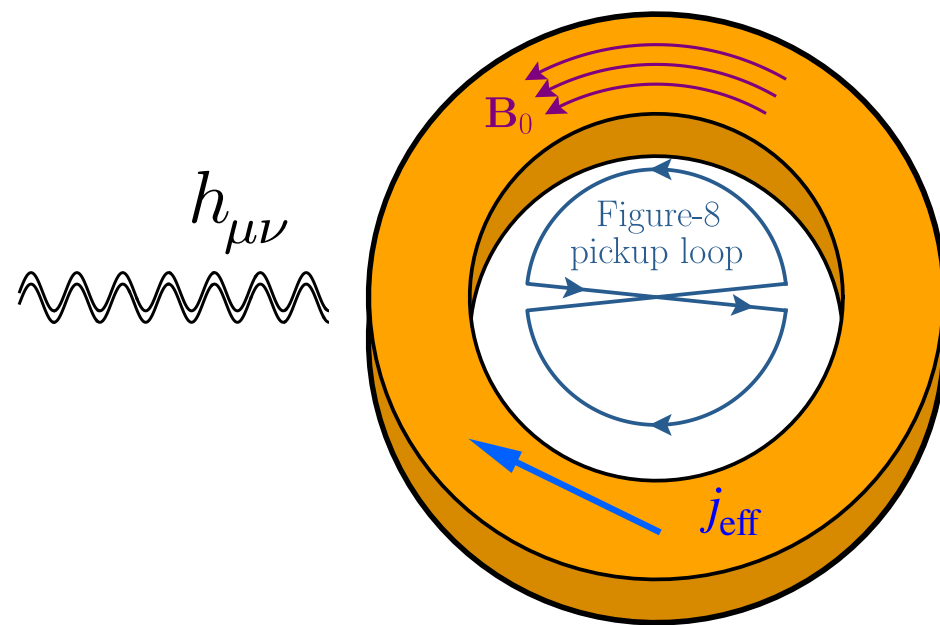
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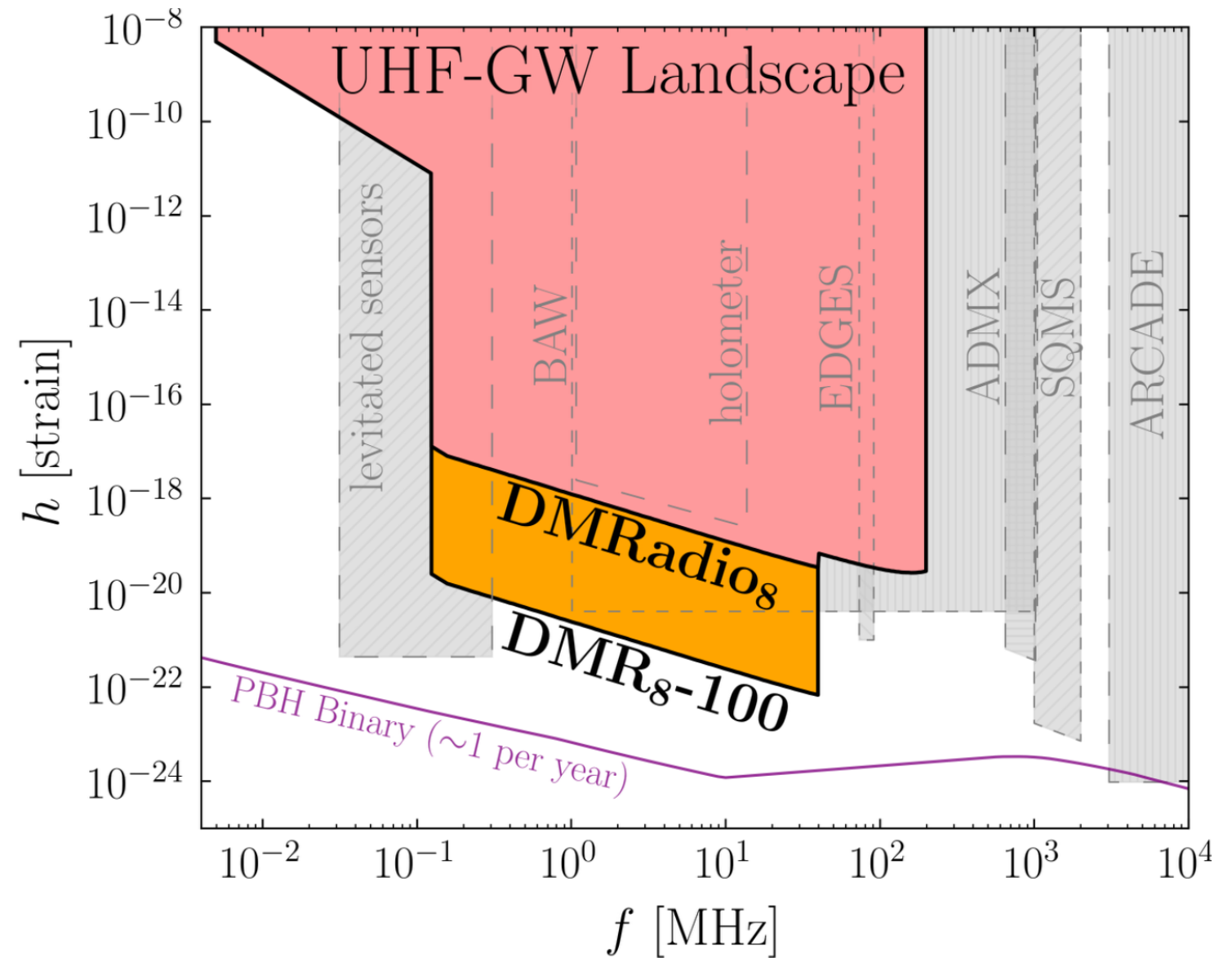
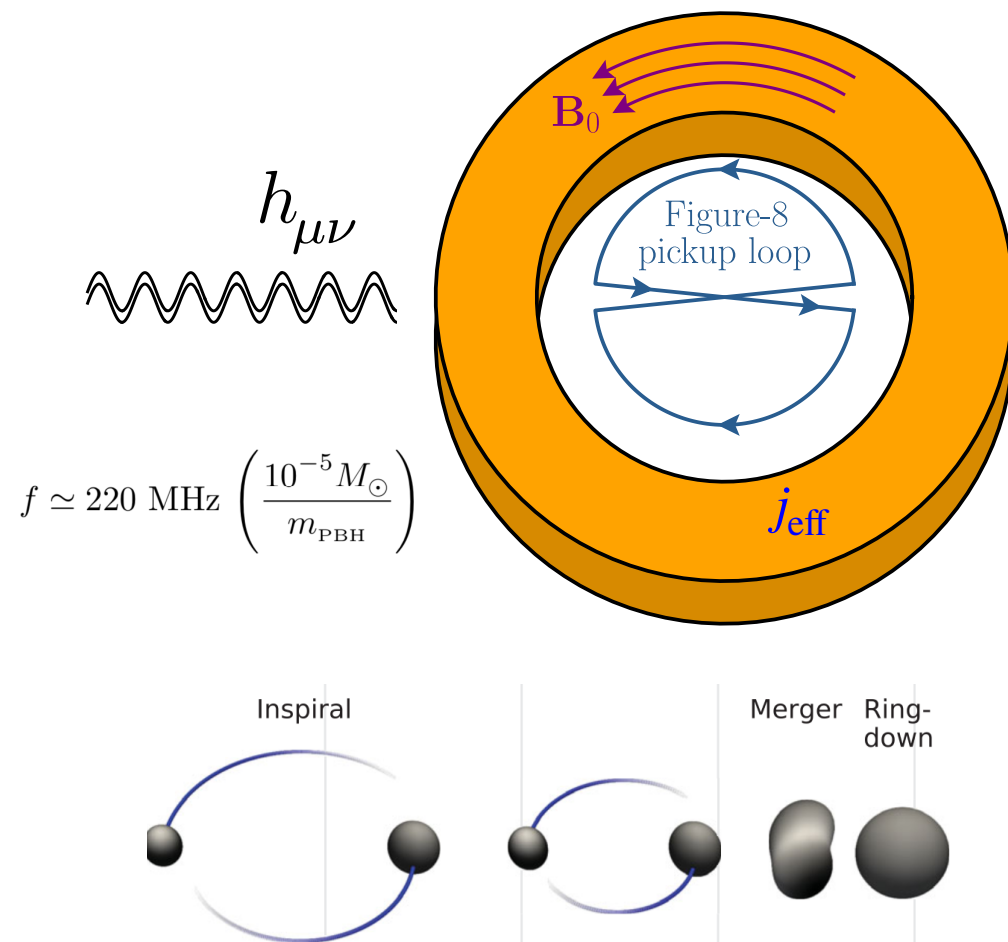


$$\Phi_8 \approx \frac{e^{-i\omega t}}{3\sqrt{2}} \omega^2 B_{\max} r^3 R s_{\theta_h} \left(h^\times s_{\phi_h} - h^+ c_{\theta_h} c_{\phi_h} \right)$$

Small modification allows to measure both polarizations

Gravitational waves in haloscopes

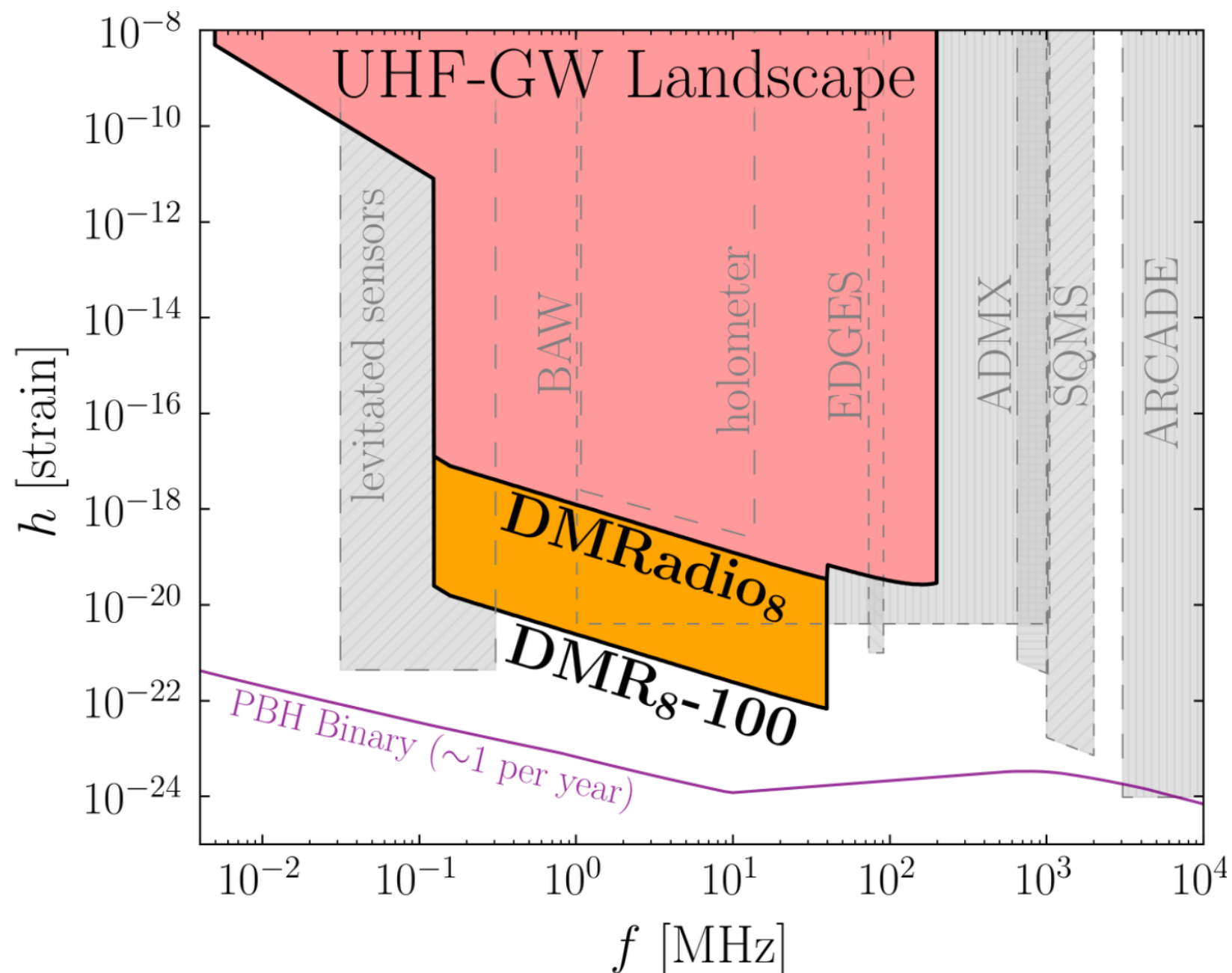
Domcke, CGC, Rodd, 2202.00695



Up-to-date estimate of PBH in binaries
and their expected merger rate accounting
for the local overdensity in the Milky Way

See also 2205.02153 by Franciolini, A. Maharana, and F. Muia,

Conclusions



Axion experiments may discover not only **dark matter**, but also exotic sources of **gravitational waves**

Different experimental proposals have coalesced on a strain sensitivity of 10^{-22} for MHz GWs, still orders of magnitude away from signals of the early Universe. Whether we can hope to probe such strain sensitivities remains to be determined.

The nucleosynthesis bound

[A. Ejlli](#) , [D. Ejlli](#), [A. M. Cruise](#), [G. Pisano](#) & [H. Grote](#)

[The European Physical Journal C](#) **79**, Article number: 1032 (2019)

