Prospects of detecting GWs from primordial black holes in axion haloscopes.

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Camilo García Cely

Ramón y Cajal Researcher

IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

VNIVERSITAT DE VALÈNCIA

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

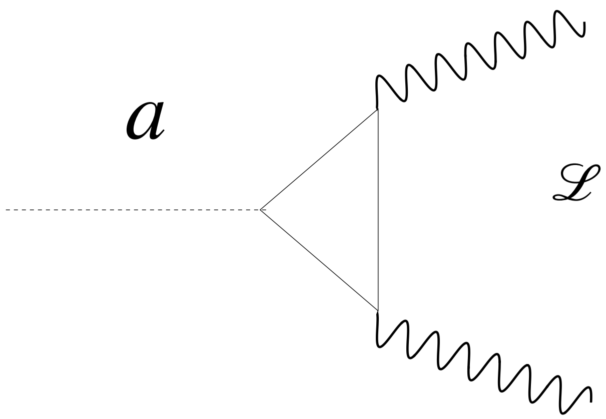
- Motivation: what is an axion and how do people search for them?
- Adapting axion experiments to detect gravitational waves
- Gravitational waves from primordial black holes
- Conclusions

Motivation

What is an axion and how do people search for them?

What is an axion?

- Pseudoscalar field



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

- 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.

$$\nabla \cdot \mathbf{B} = 0$$

Sikivie, 1983

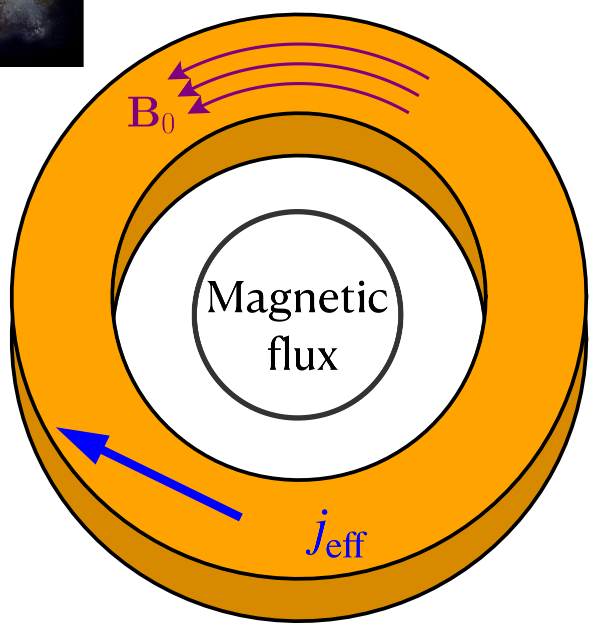
$$\nabla \times \mathbf{E} + \partial_t \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{E} = j^0$$

$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = \mathbf{j}$$

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

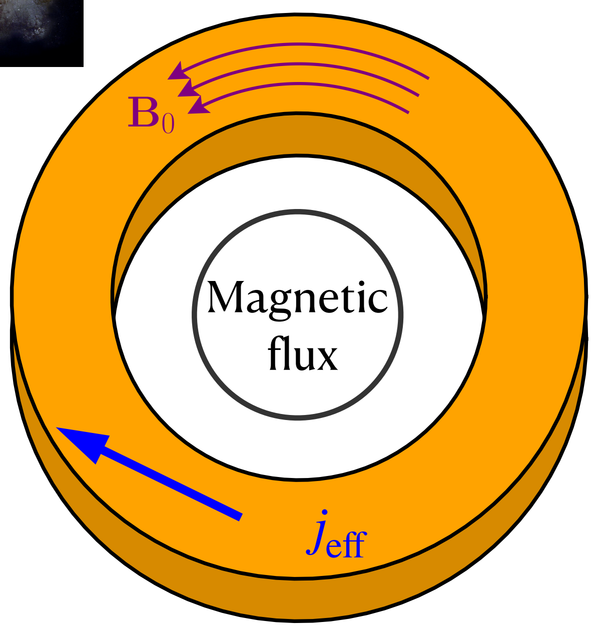
DMRadio program

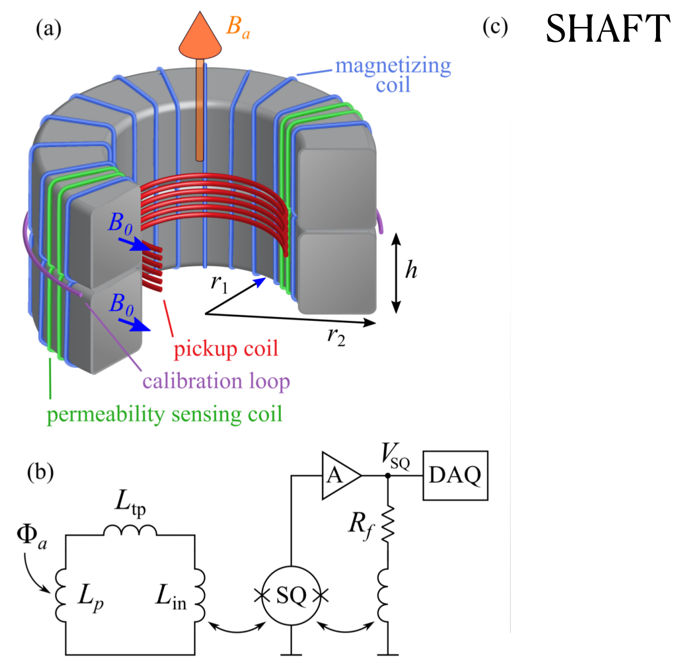


$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = \underbrace{g_{a\gamma\gamma}\, \partial_t a\, \mathbf{B_0}}_{j_{\text{eff}}}$$

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

DMRadio program





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

physics https://doi.org/

Search for axion-like dark matter with ferromagnets

Alexander V. Gramolin[1], Deniz Aybas[1,2], Dorian Johnson[1], Janos Adam[1] and Alexander O. Sushkov[1,2,3]

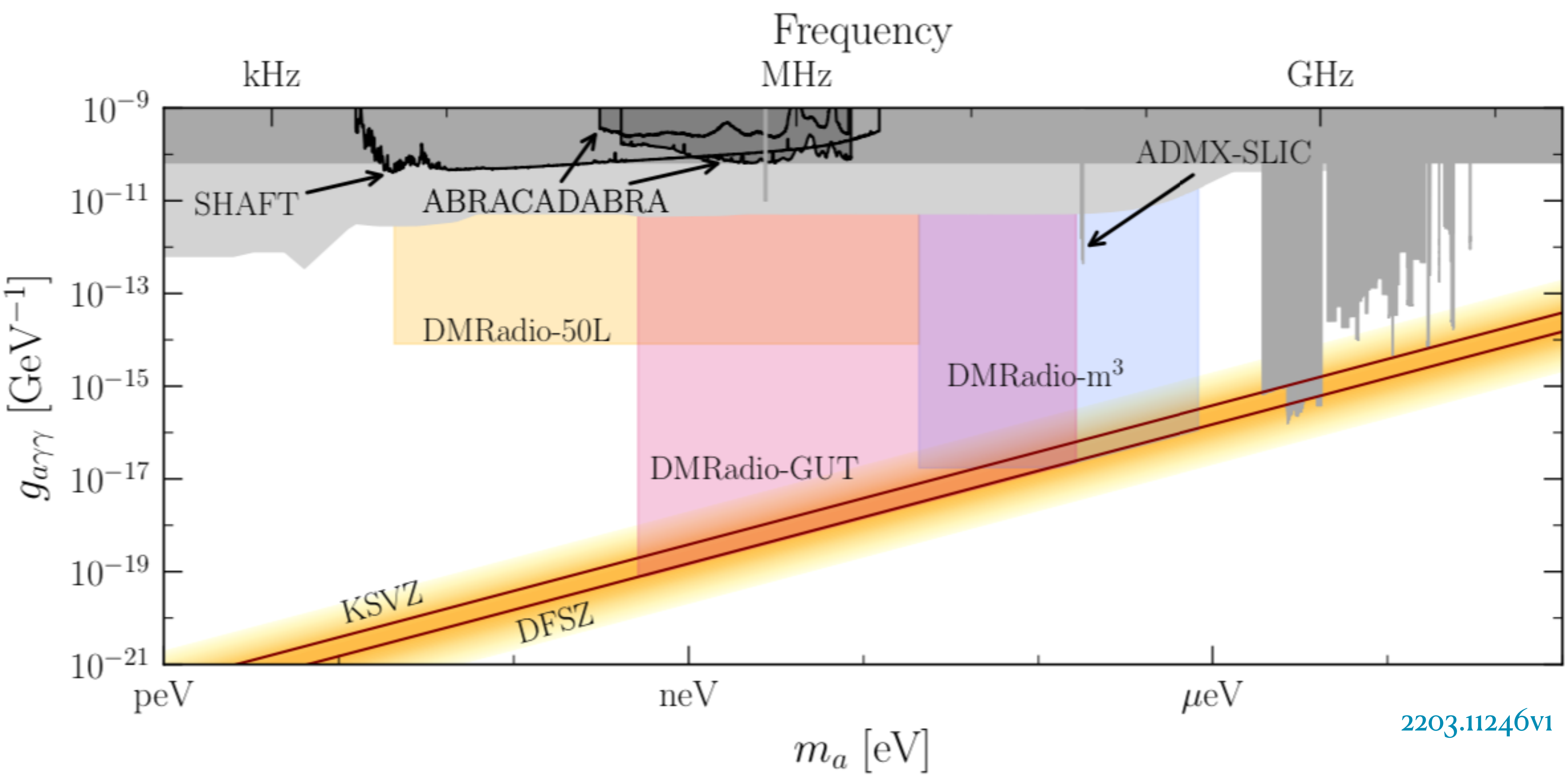
PRL 117, 141801 (2016) PHYSICAL REVIEW LETTERS week ending 30 SEPTEMBER 2016

Broadband and Resonant Approaches to Axion Dark Matter Detection

Yonatan Kahn,[1,*] Benjamin R. Safdi,[2,†] and Jesse Thaler[2,‡]
[1]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA
[2]Center 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



2203.11246v1

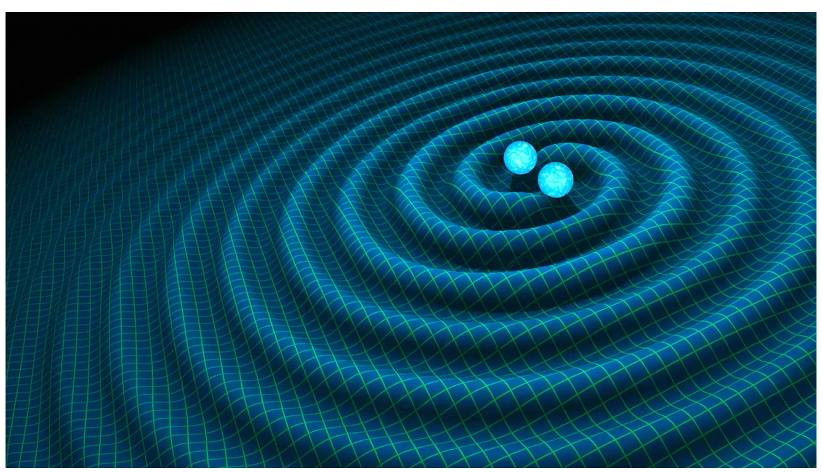
Camilo García Cely, University of Valencia

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.

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad \left| h_{\mu\nu} \right| \ll 1$$

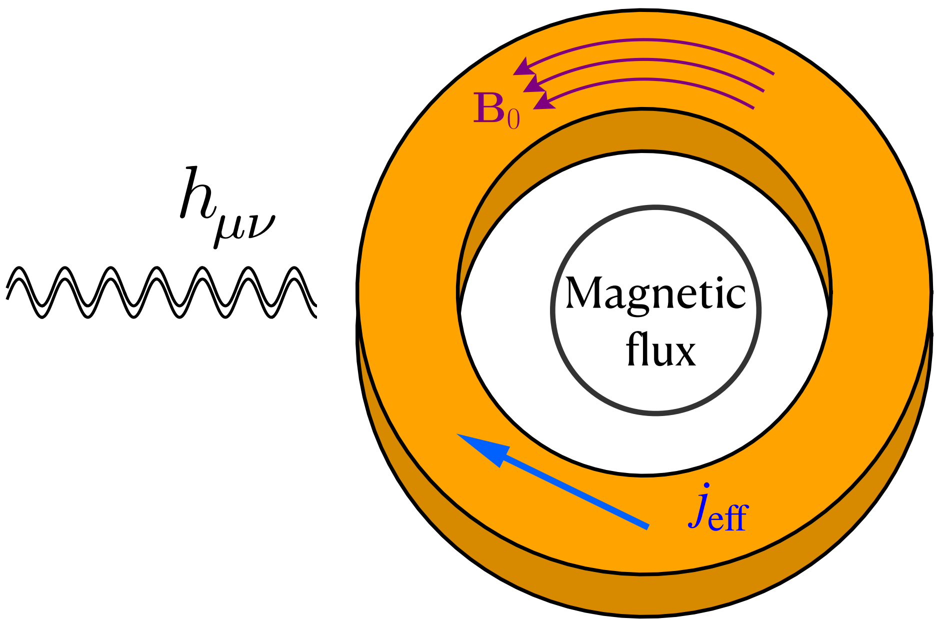


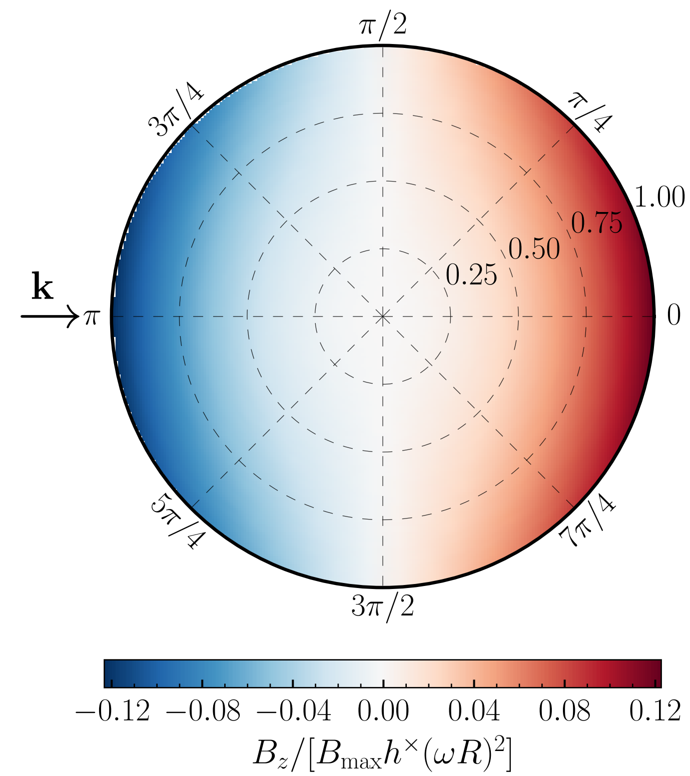
$$j^{\mu}_{\text{eff}} = \partial_\nu \left(-\frac{1}{2} h\, F^{\mu\nu} + F^{\mu\alpha} h^{\nu}{}_{\alpha} - F^{\nu\alpha} h^{\mu}{}_{\alpha} \right)$$

See talk by Diego Blas

Adapting axion experiments to detect GWs

Domcke, CGC, Rodd, 2202.00695





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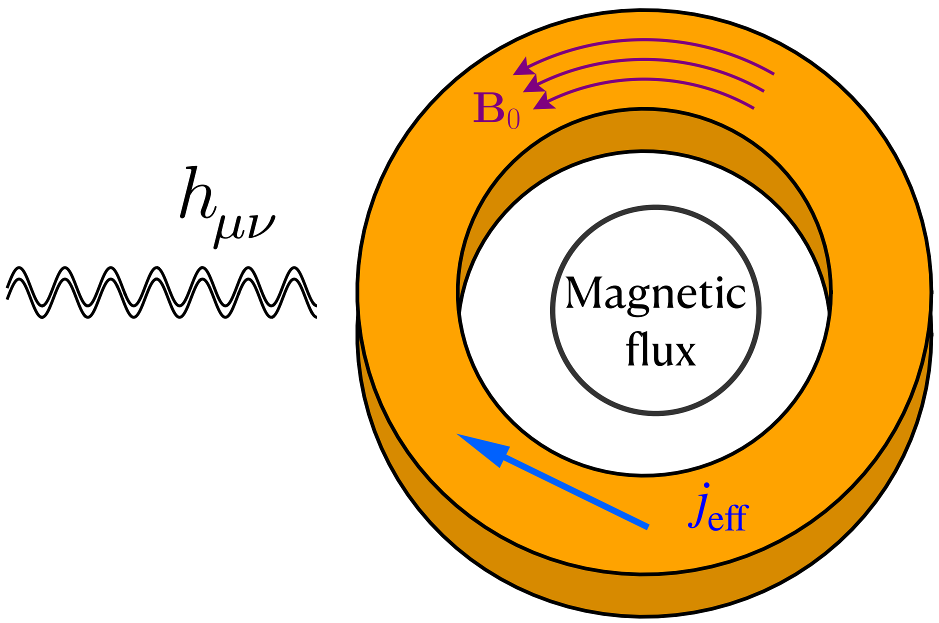
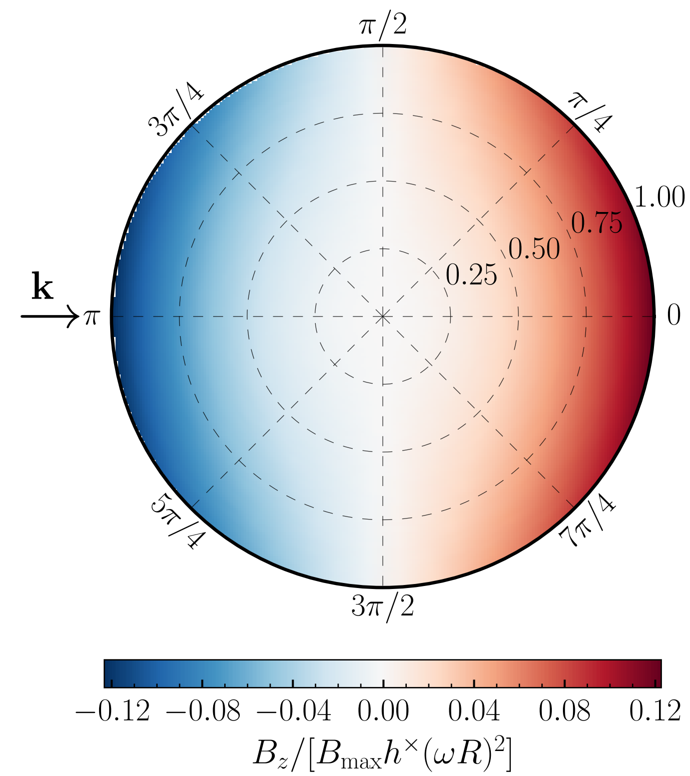
Adapting axion experiments to detect GWs

Domcke, CGC, Rodd, 2202.00695





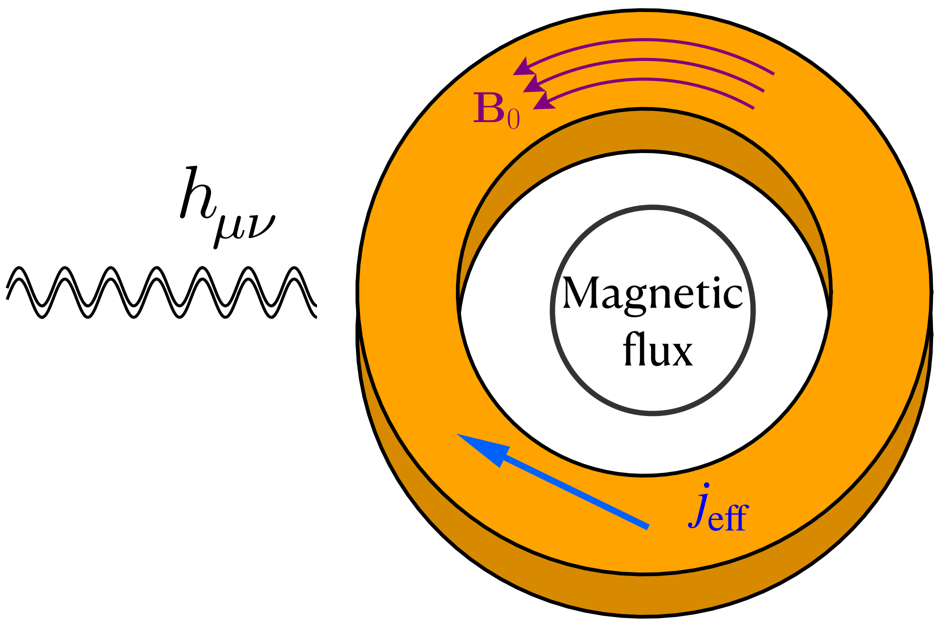
$$\Phi \approx \frac{\mathrm{i}e^{-\mathrm{i}\omega t}}{16\sqrt{2}} h^\times \omega^3 B_{\rm max} \pi r^2 R a(a+2R) s_{\theta_h}^2$$

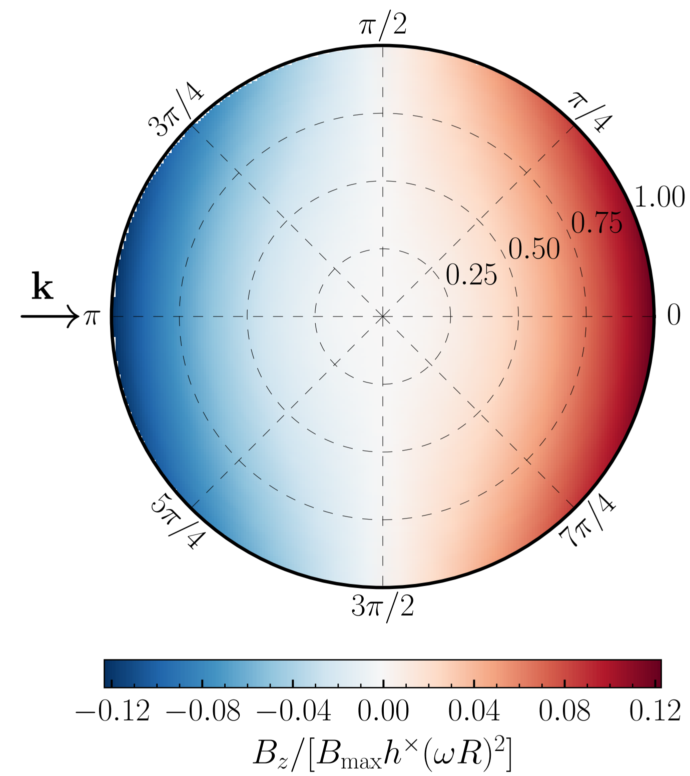
Only one polarization

Suppression at small frequencies

Adapting axion experiments to detect GWs

Domcke, CGC, Rodd, 2202.00695





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

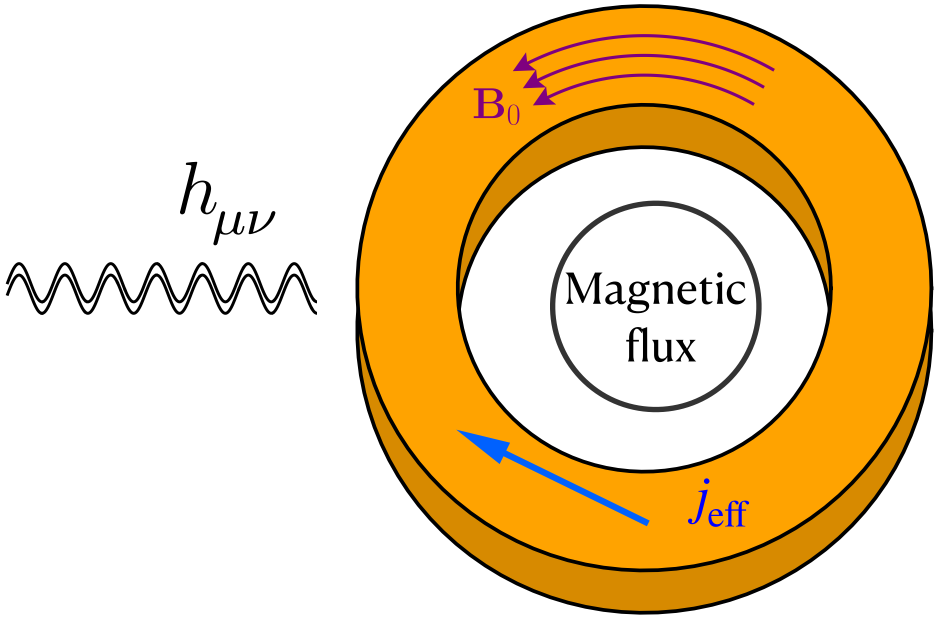
Only one polarization

Suppression at small frequencies

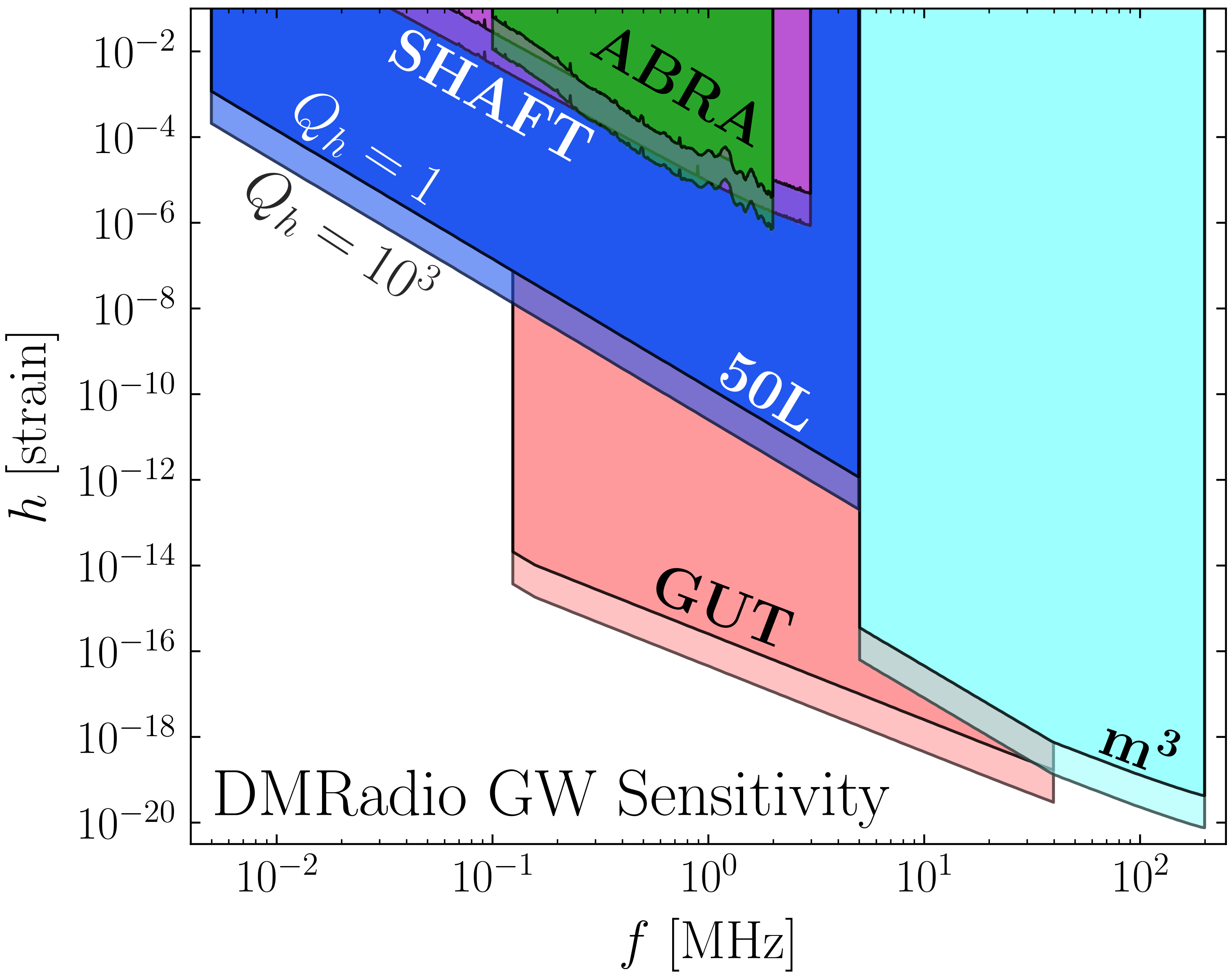
$$\Phi_{\mathrm{axions}} \approx e^{-\mathrm{i}\omega t} g_{a\gamma\gamma}\sqrt{2\rho_{\mathrm{DM}}} B_{\mathrm{max}}\pi r^2 R$$

The sensitivity scaling with the volume is faster than for axions

Adapting axion experiments to detect GWs



Domcke, CGC, Rodd, 2202.00695



Gravitational waves from primordial black holes

High-frequency gravitational waves

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

Part of a collection:

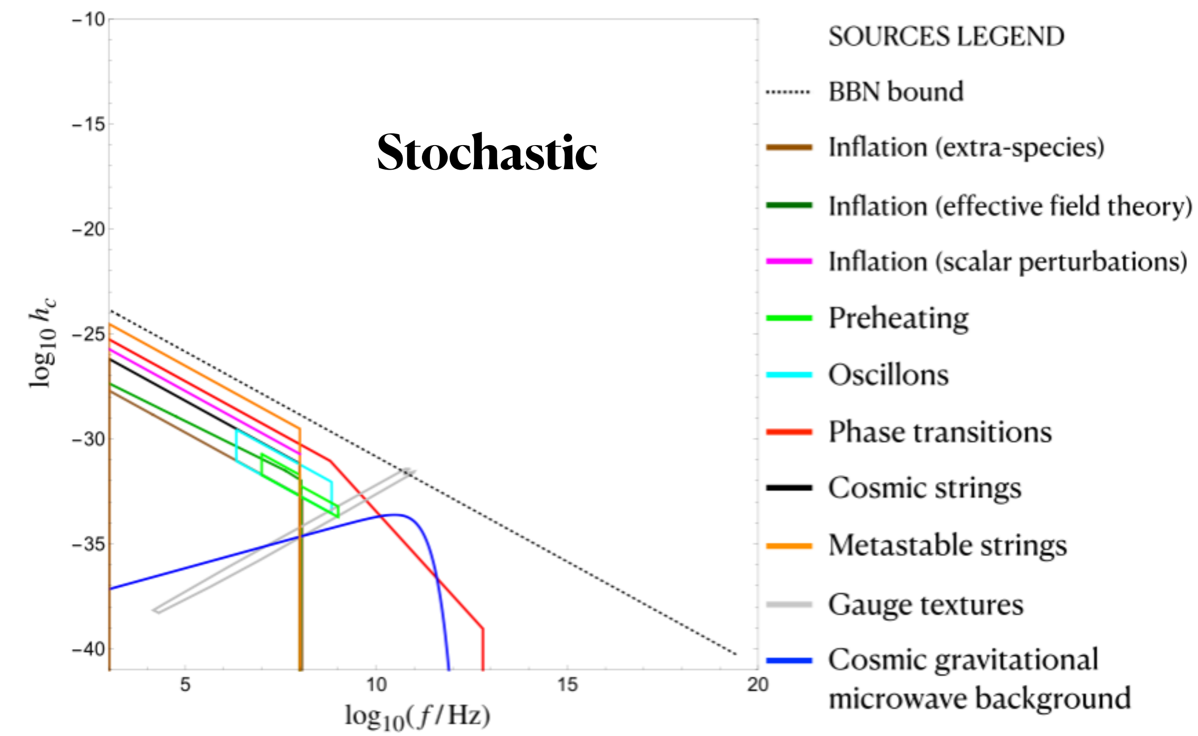
Gravitational Waves

Review Article | Open Access | Published: 06 December 2021

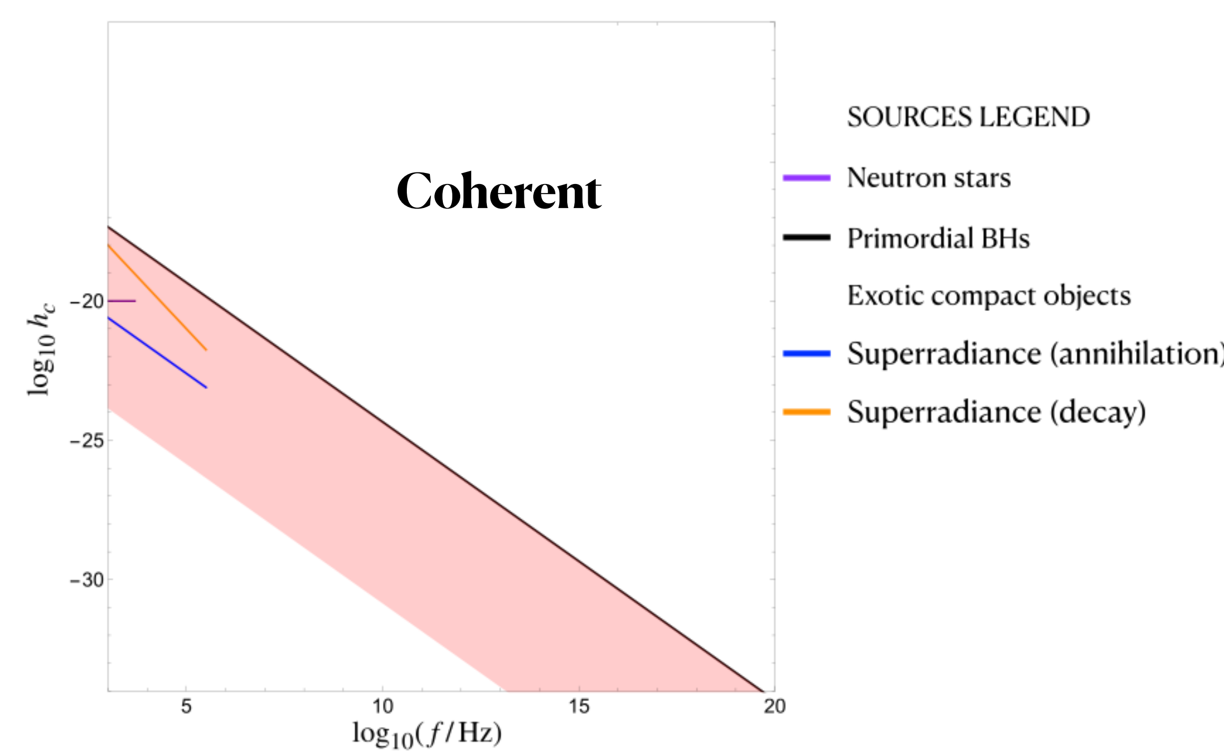
Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies

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



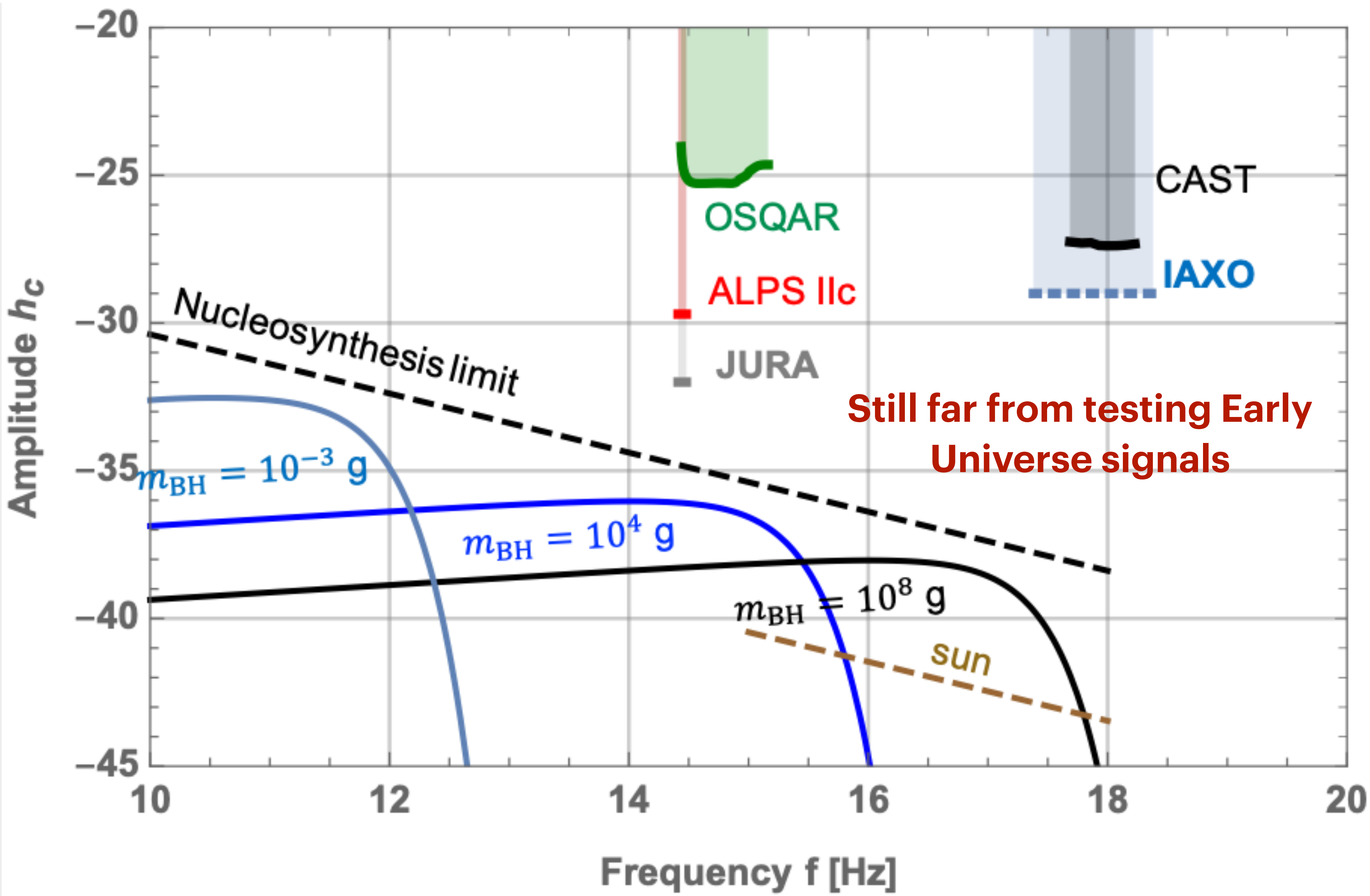
A growing community is seriously considering the search of high frequency gravitational waves



The nucleosynthesis bound

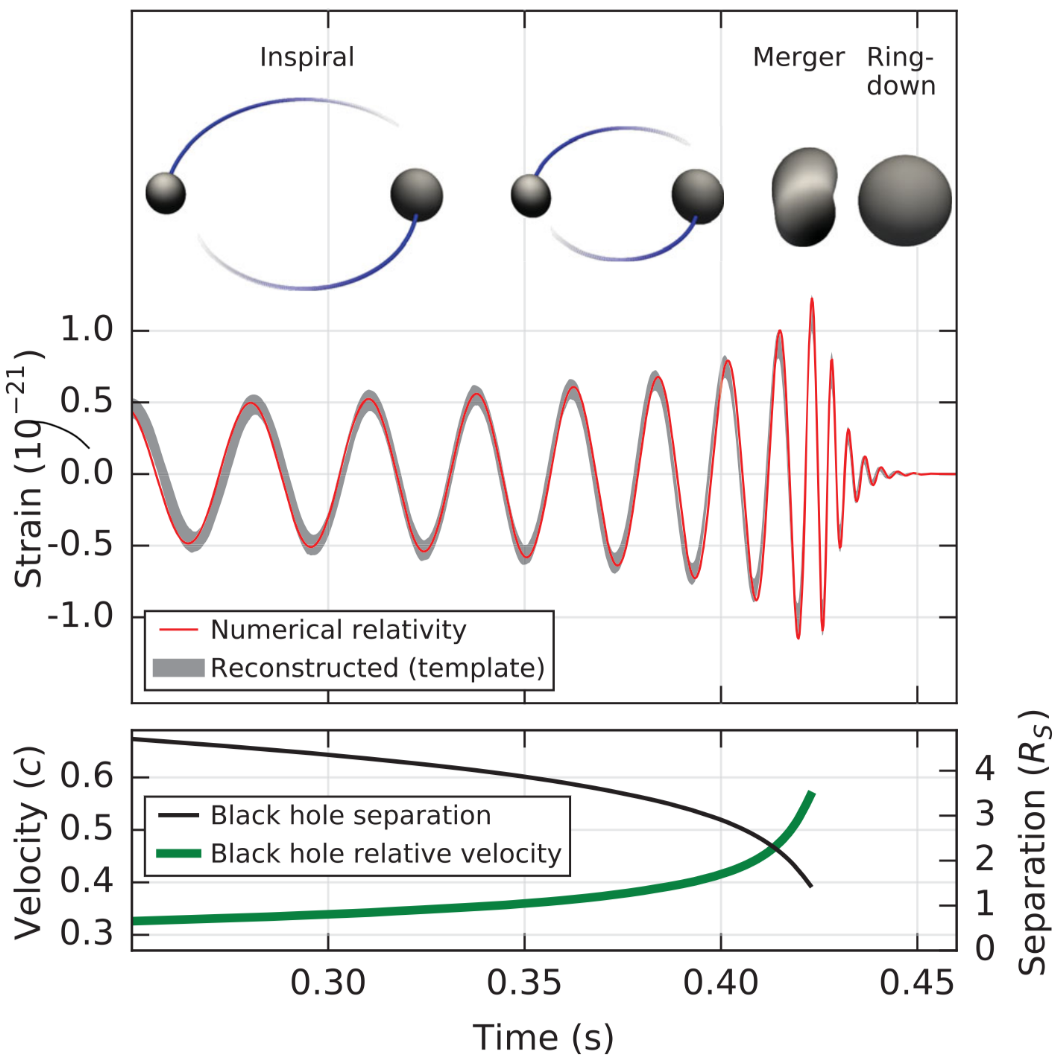
A. Ejlli, D. Ejlli, A. M. Cruise, G. Pisano & H. Grote

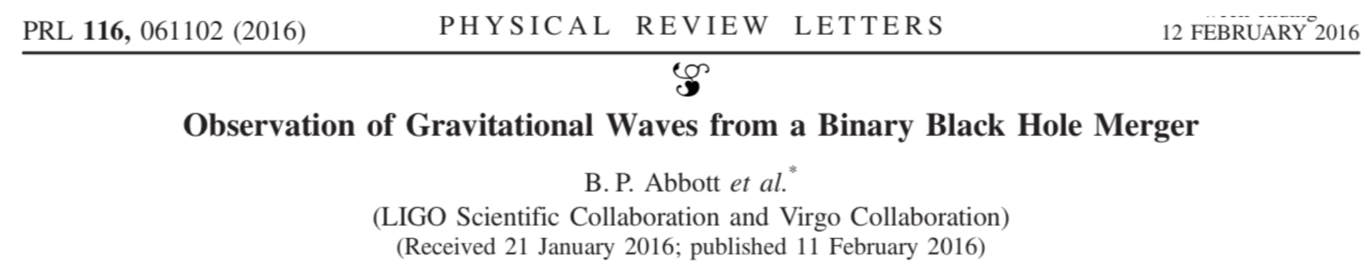
The European Physical Journal C **79**, Article number: 1032 (2019)



Still far from testing Early Universe signals

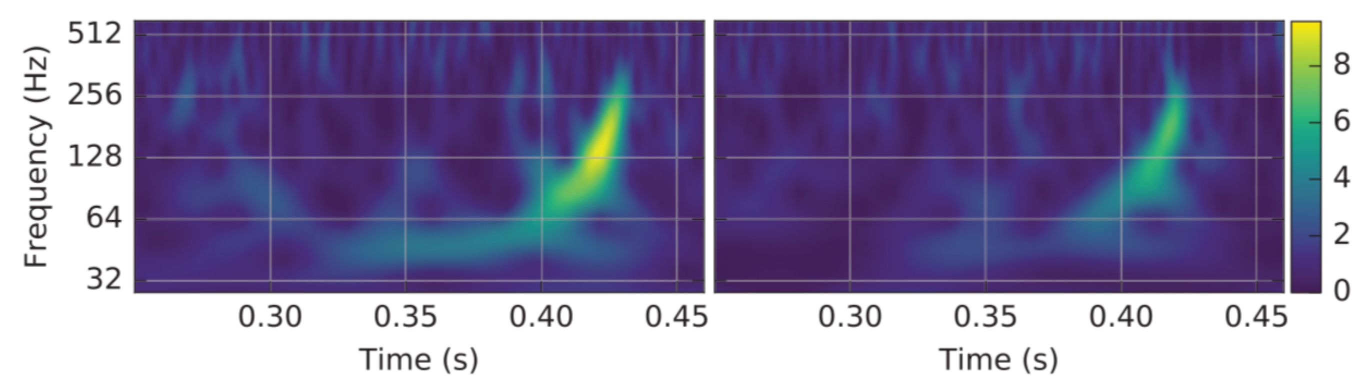
Gravitational waves from black holes




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)

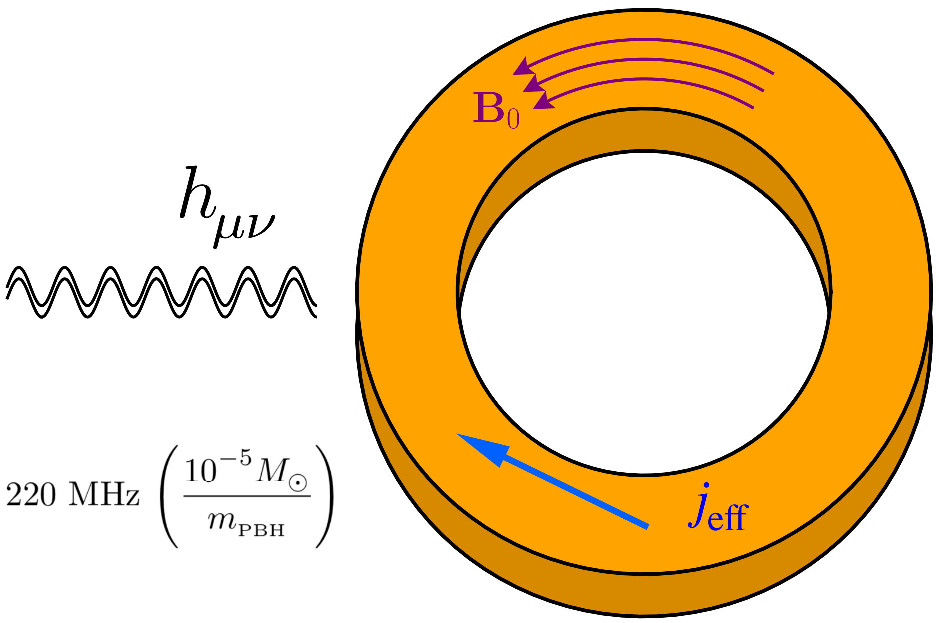


$$f \approx 2.2 \text{ kHz} \left(\frac{M_\odot}{m_{\rm BH}}\right)$$

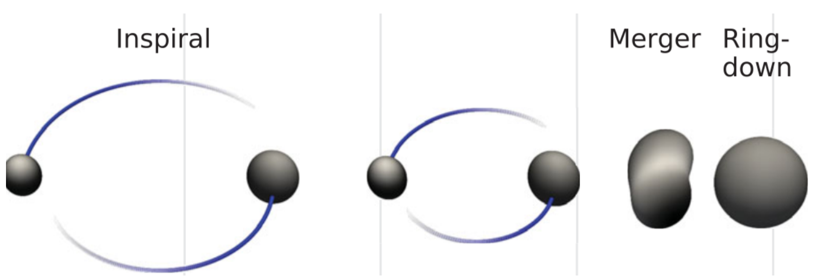
Subsolar primordial black holes can produce high frequency GWs

Haloscopes based on lumped-element detectors

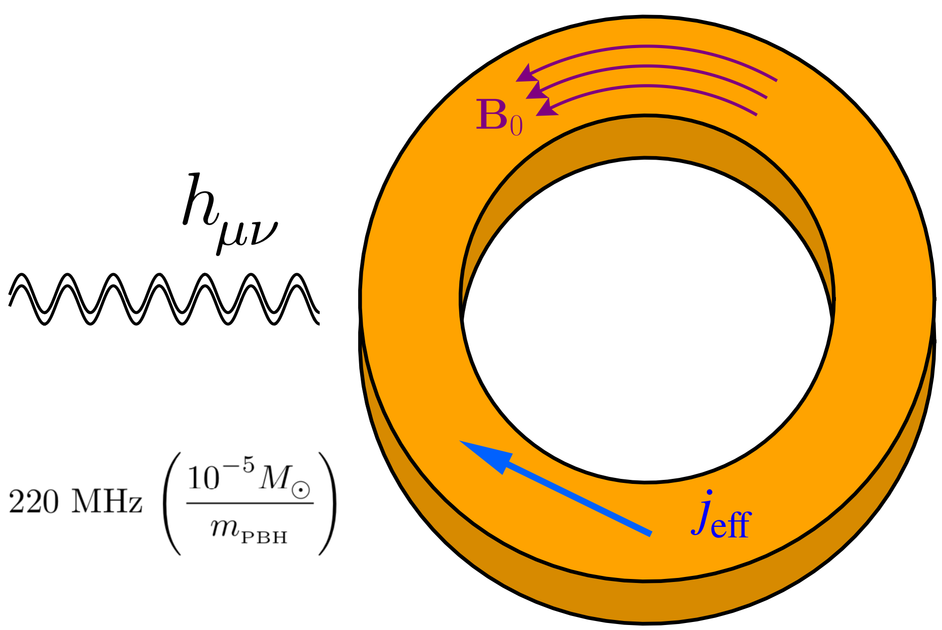
Domcke, CGC, Rodd, 2202.00695



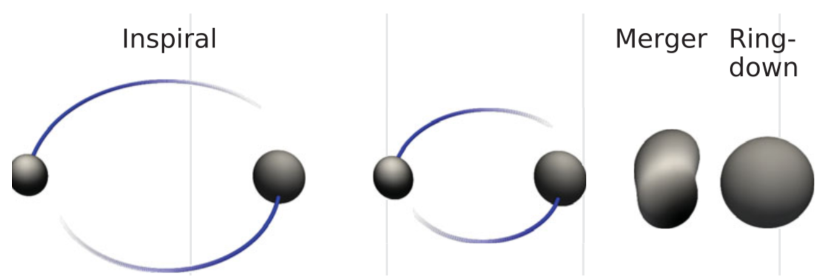
$$f \simeq 220\ \text{MHz} \left(\frac{10^{-5} M_\odot}{m_{\rm PBH}}\right)$$



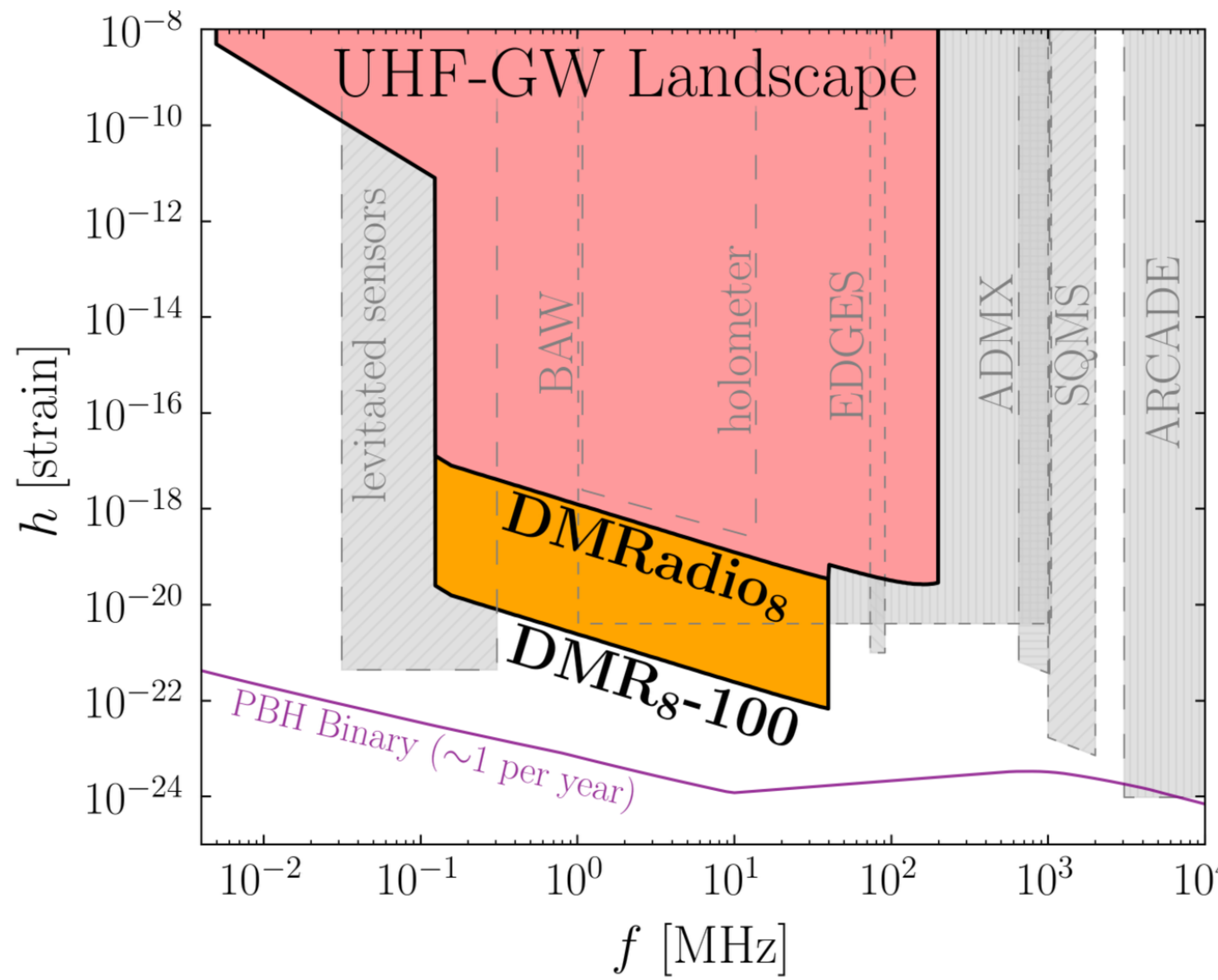
Haloscopes based on lumped-element detectors



$$f \simeq 220\ \text{MHz}\left(\frac{10^{-5} M_\odot}{m_{\text{PBH}}}\right)$$



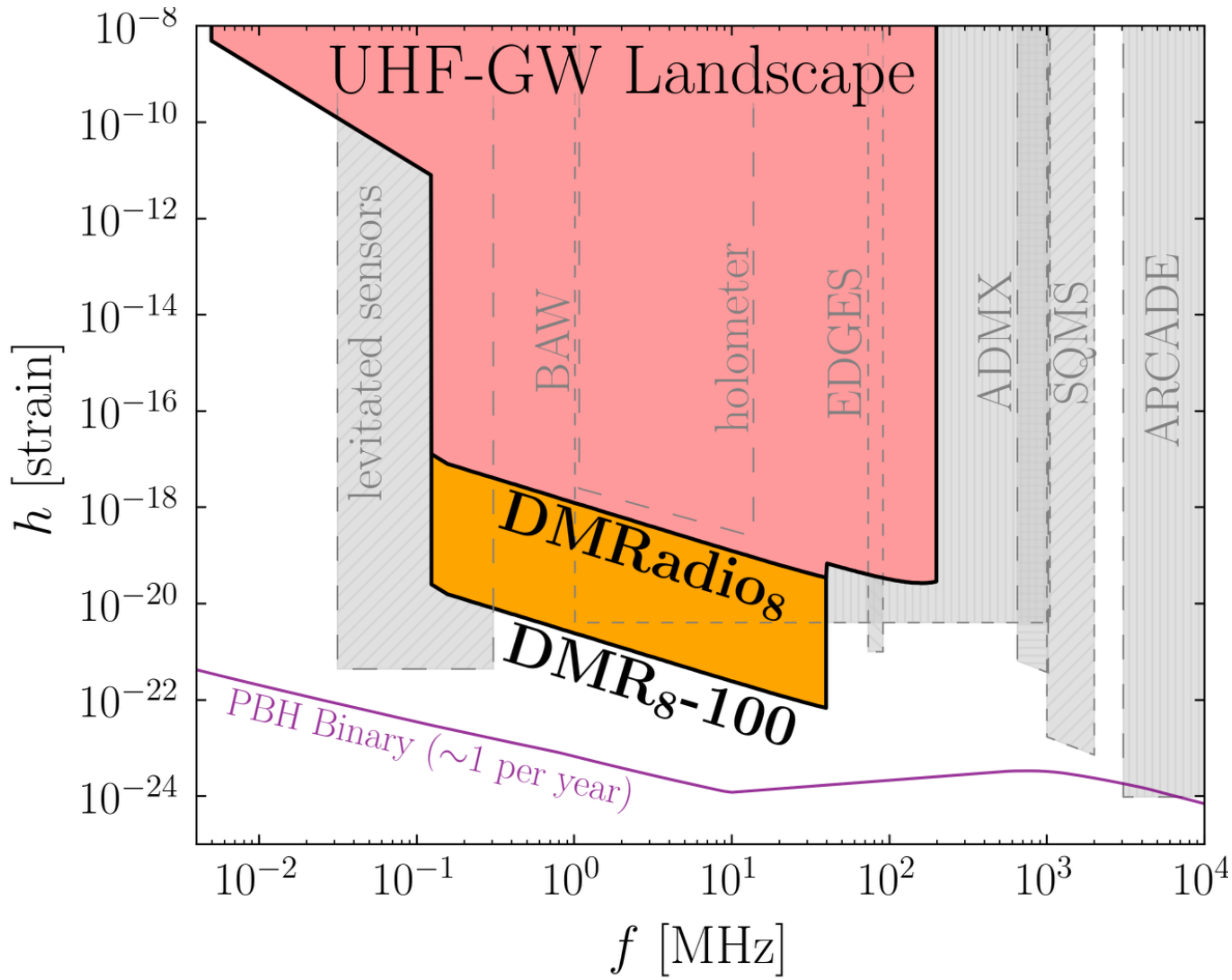
Domcke, CGC, Rodd, 2202.00695



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

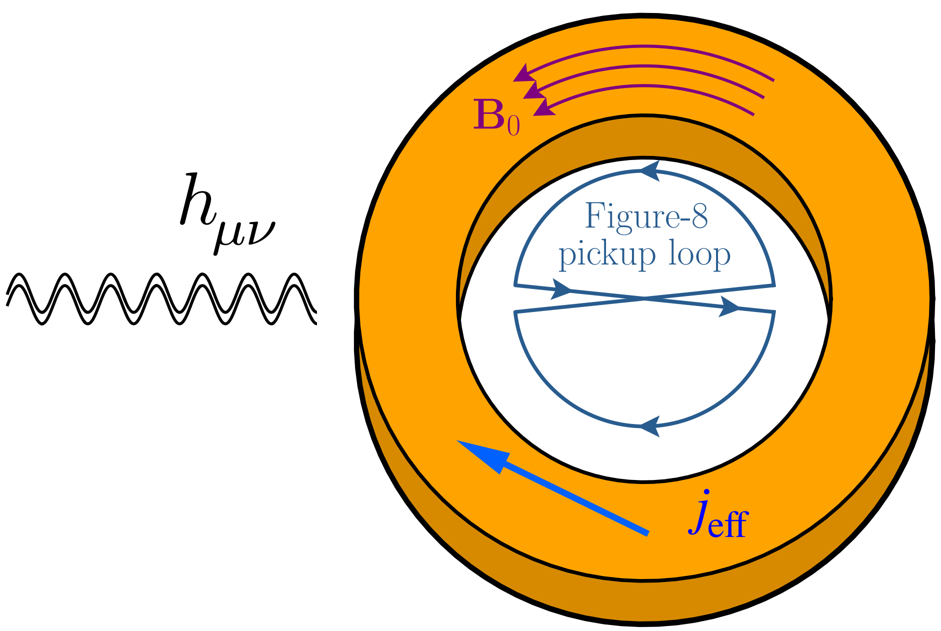


Axion experiments may discover not only dark matter, but also exotic sources of gravitational waves

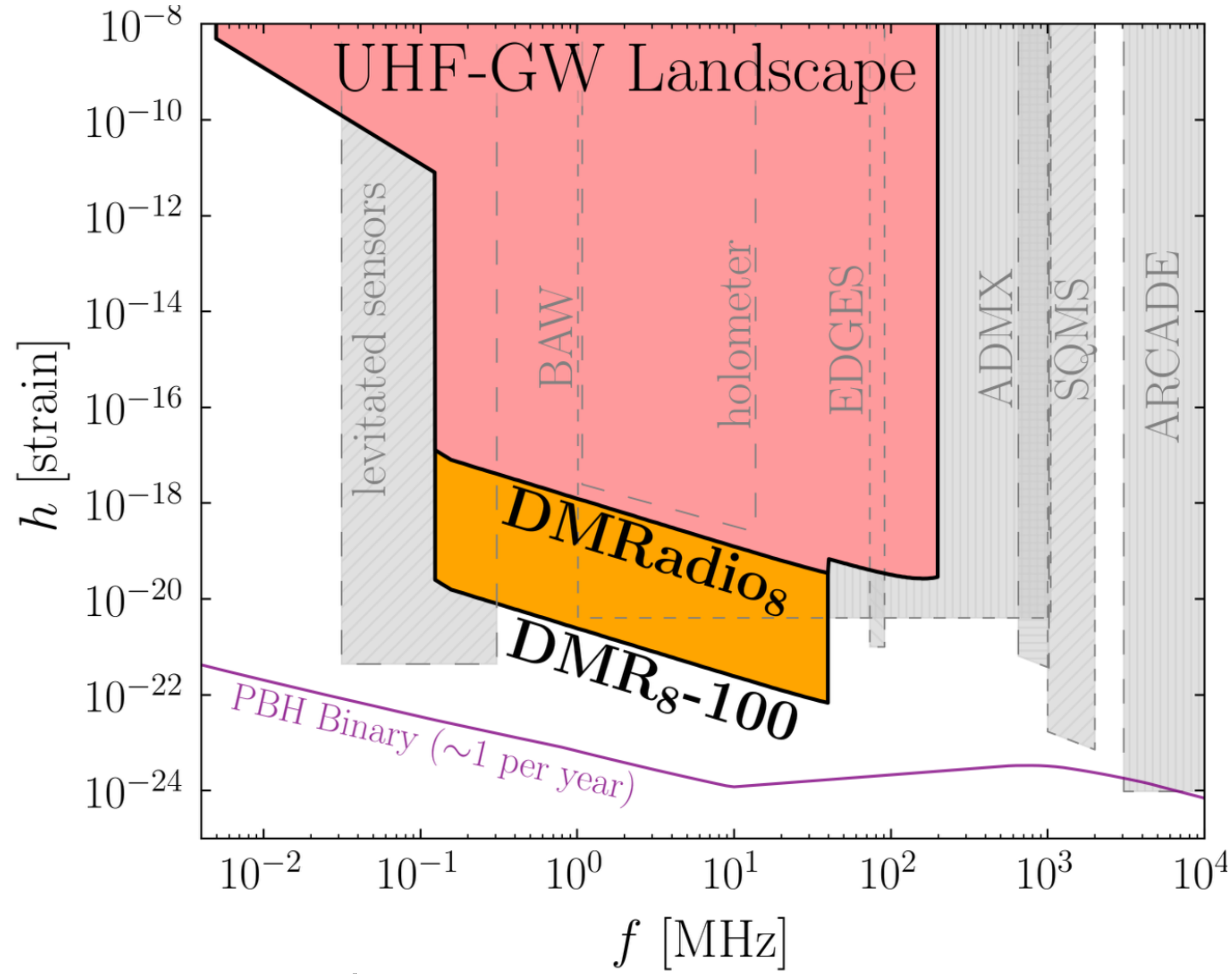
Different experimental proposals have coalesced on a strain sensitivity of 10^{-22} for MHz GWs, still orders of magnitude away from signals of the early Universe. Whether we can hope to probe such strain sensitivities remains to be determined.

Camilo García Cely, University of Valencia

Haloscopes based on lumped-element detectors



Domcke, CGC, Rodd, 2202.00695



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

Small modification allows to measure both polarizations

Camilo García Cely, University of Valencia