Detection of gravitational waves with axion haloscopes

Camilo A. Garcia Cely

Ramón y Cajal Fellow

IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

VNIVERSITAT DE VALÈNCIA

April 28, 2022

Gravitational Waves

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- Einstein provided a firm theoretical background for them (1916)

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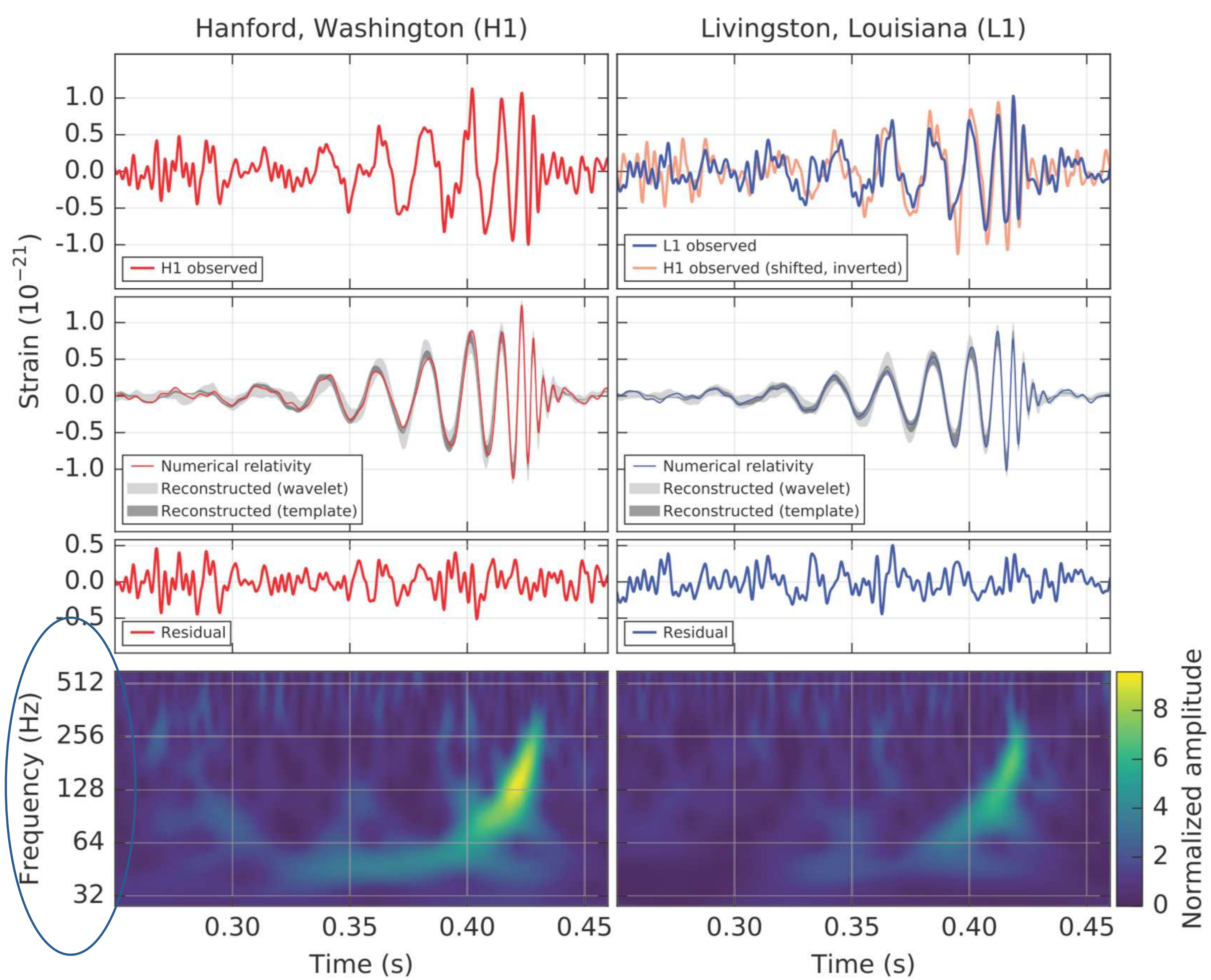
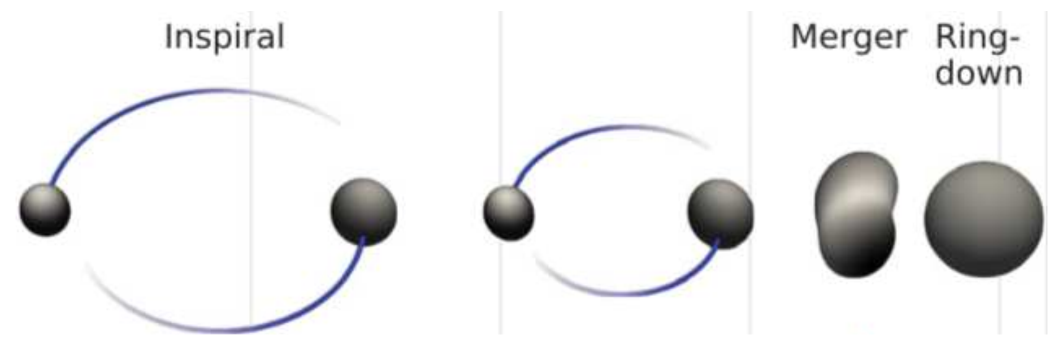
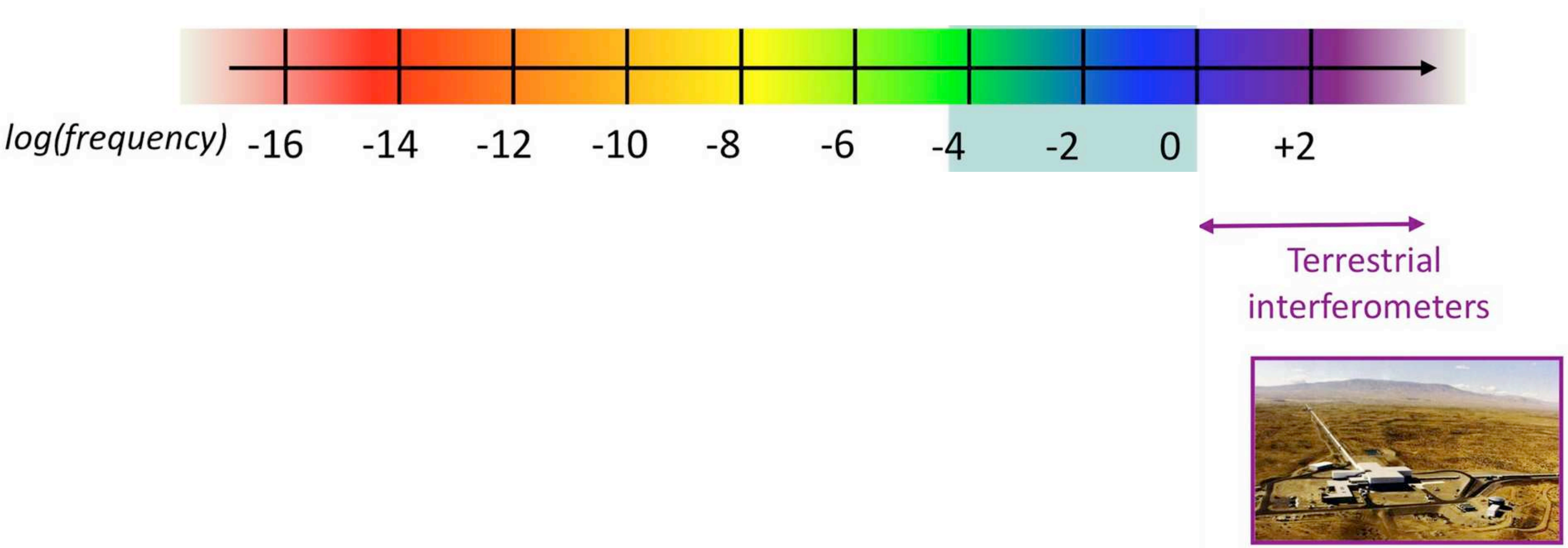
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016





Terrestrial interferometers

Gravitational Wave Spectrum



Credit: NASA Goddard Space Flight Center

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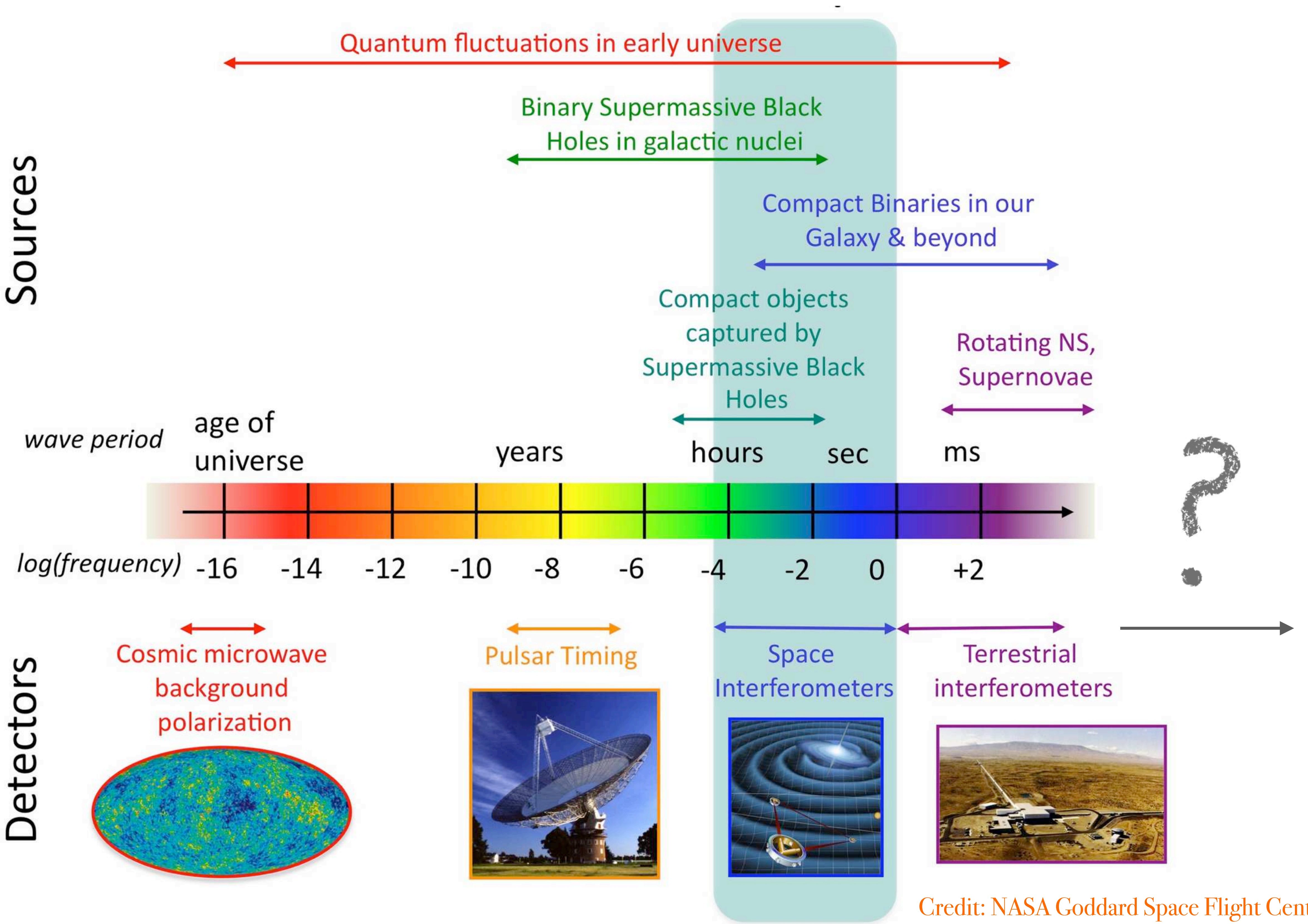

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Revisiting Gertsenhstein's ideas

SOVIET PHYSICS JETP VOLUME 16, NUMBER 2 FEBRUARY, 1963

ON THE DETECTION OF LOW FREQUENCY GRAVITATIONAL WAVES

M. E. GERTSENSHTEĬN and V. I. PUSTOVOĬT

Submitted to JETP editor March 3, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) 43, 605-607 (August, 1962)

It is shown that the sensitivity of the electromechanical experiments for detecting gravitational waves by means of piezocrystals is ten orders of magnitude worse than that estimated by Weber.[1] In the low frequency range it should be possible to detect gravitational waves by the shift of the bands in an optical interferometer. The sensitivity of this method is investigated.

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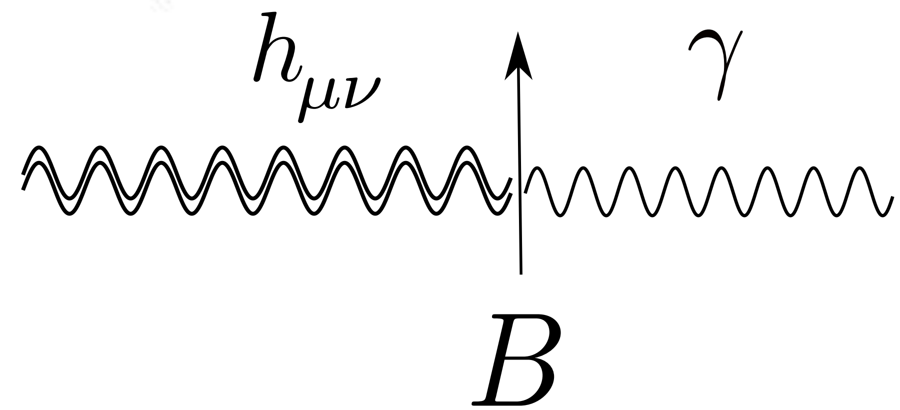
SOVIET PHYSICS JETP VOLUME 14, NUMBER 1 JANUARY, 1962



WAVE RESONANCE OF LIGHT AND GRAVITIONAL WAVES

M. E. GERTSENSHTEĬN

Submitted to JETP editor July 29, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 113-114 (July, 1961)

The energy of gravitational waves excited during the propagation of light in a constant magnetic or electric field is estimated.

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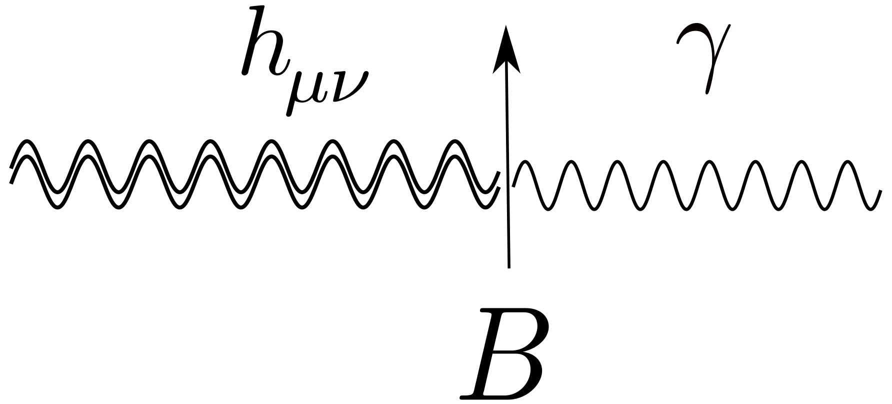

Axions

- The strong CP problem: experiments put a strong upper bound on the electric dipole of the neutron

$$\mathscr{L} = \frac{g_s^2 \theta}{32\pi^2} F^a_{\mu\nu}\tilde{F}^{a\mu\nu} \longrightarrow \frac{g_s^2 a}{32\pi^2 f} F^a_{\mu\nu}\tilde{F}^{a\mu\nu}$$

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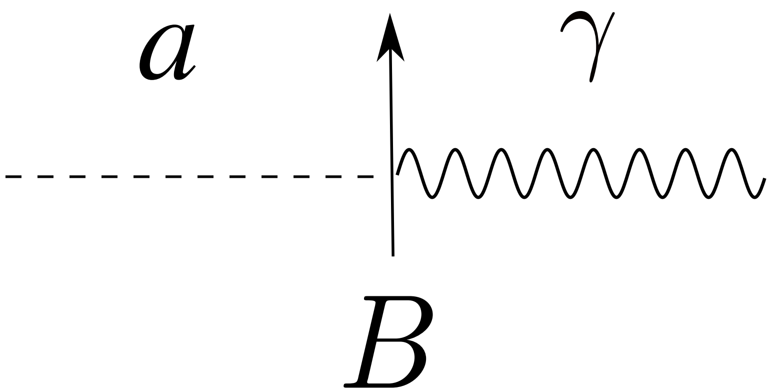

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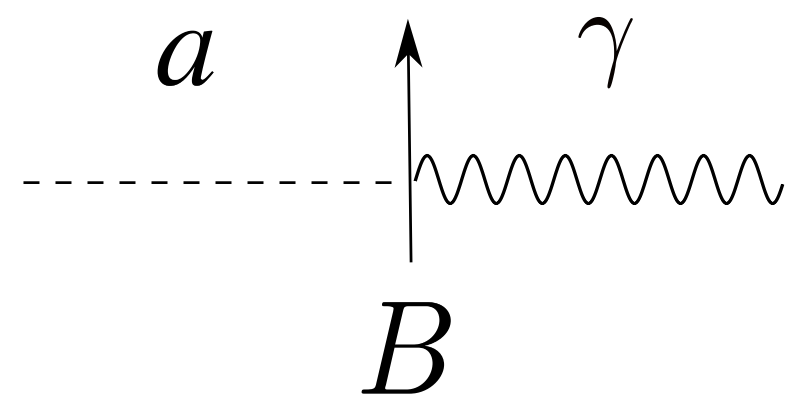

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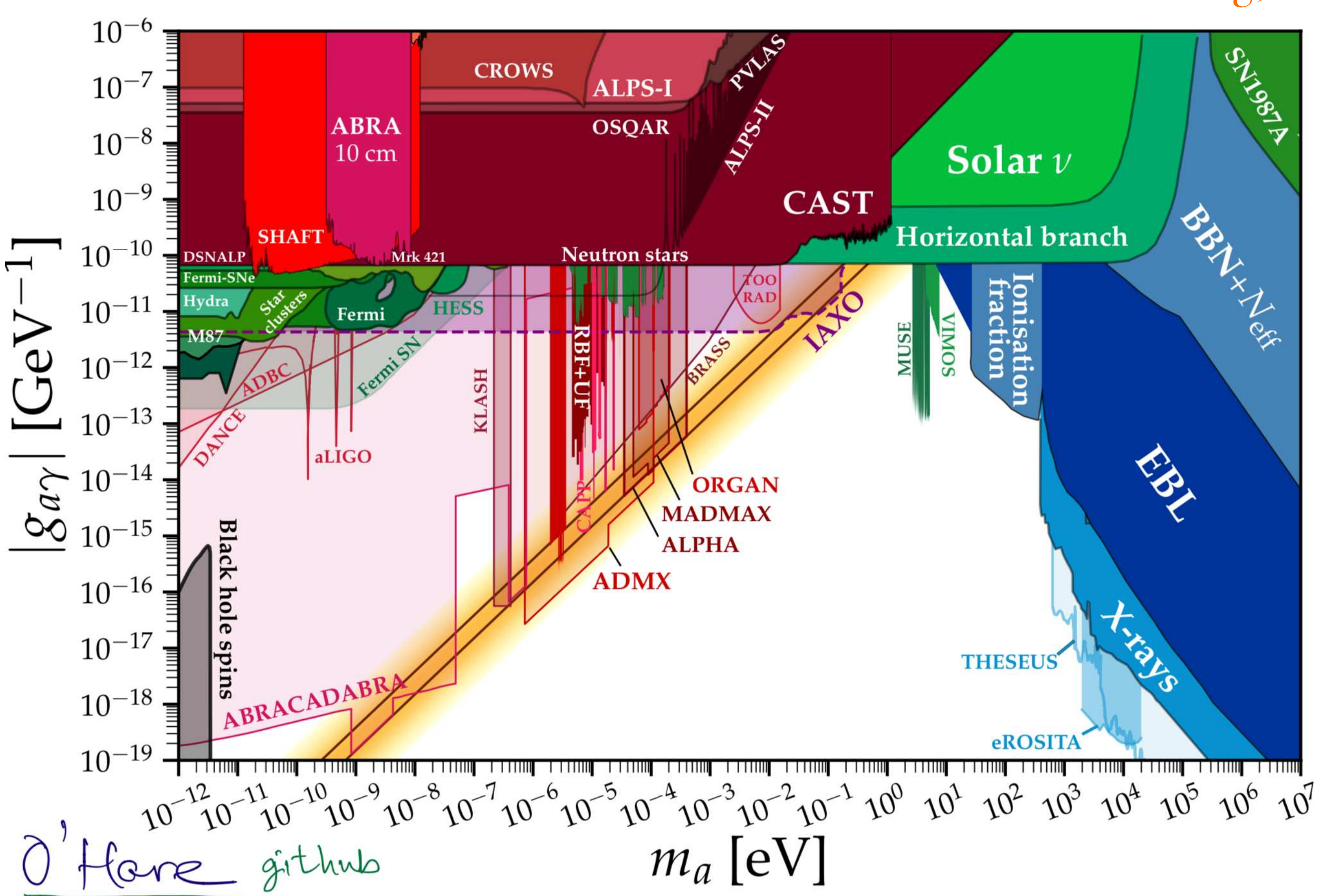

O'Hare github

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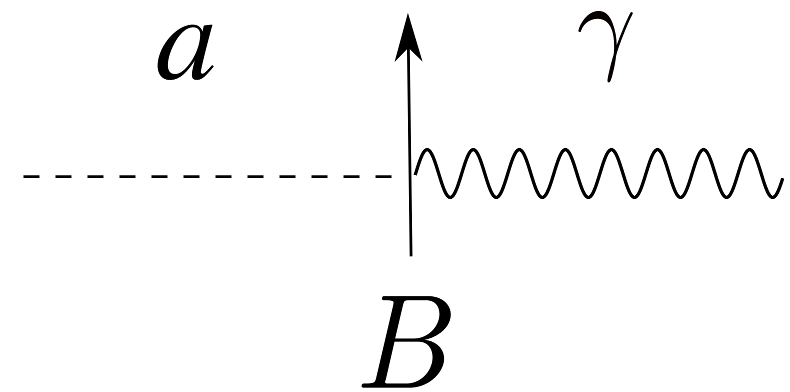

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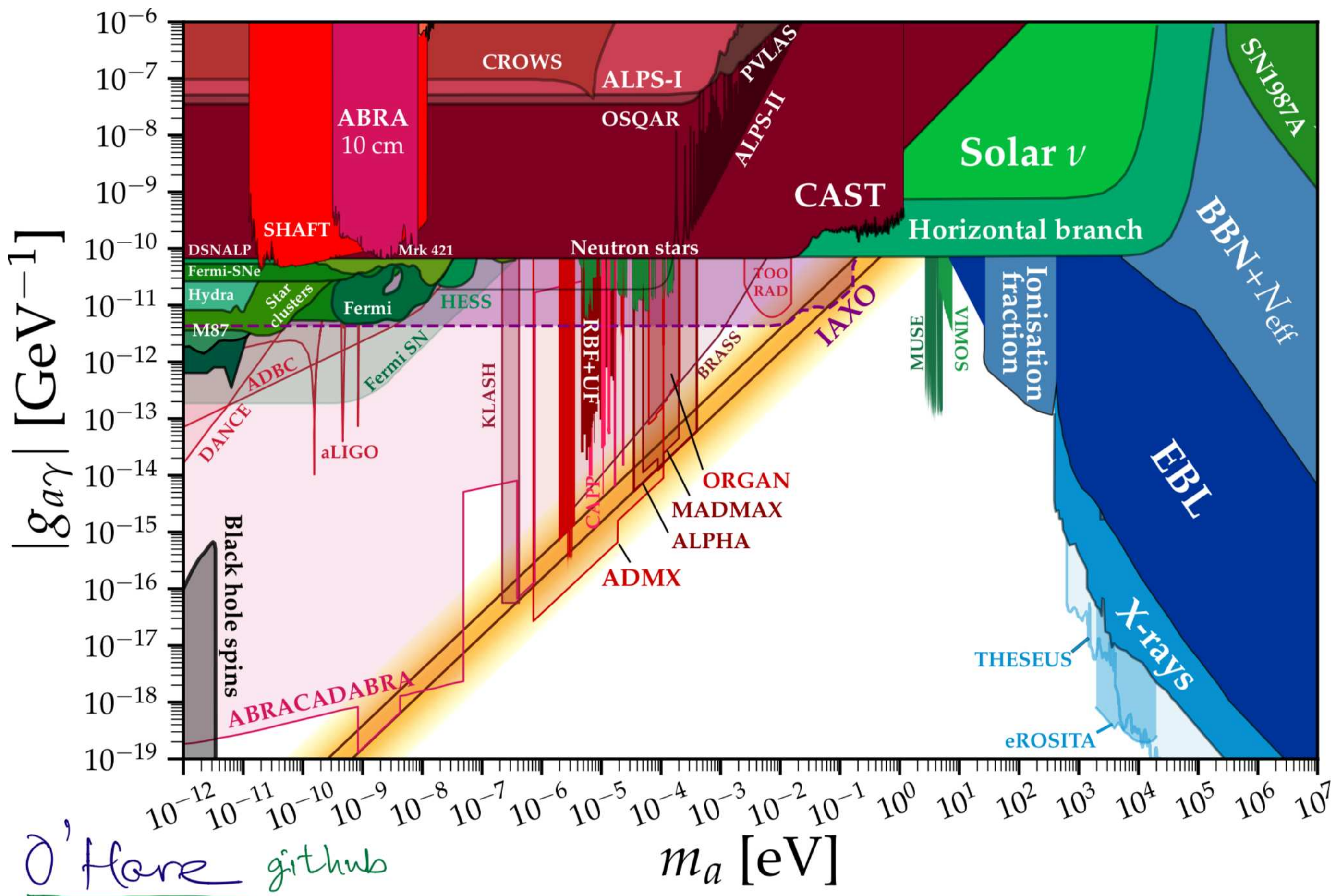

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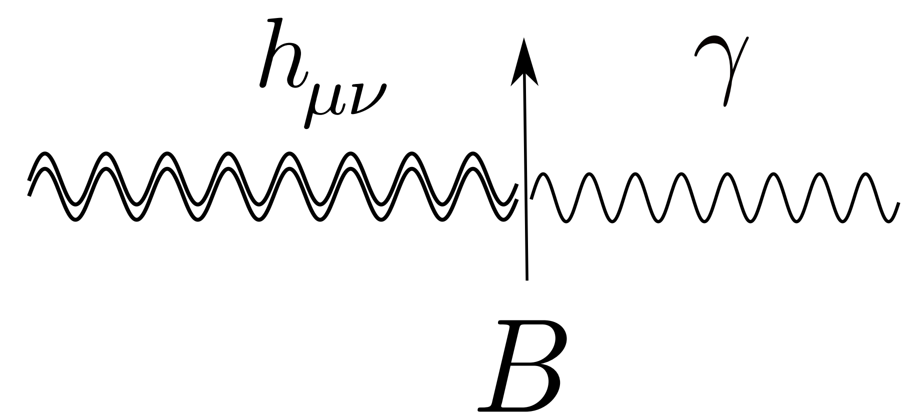
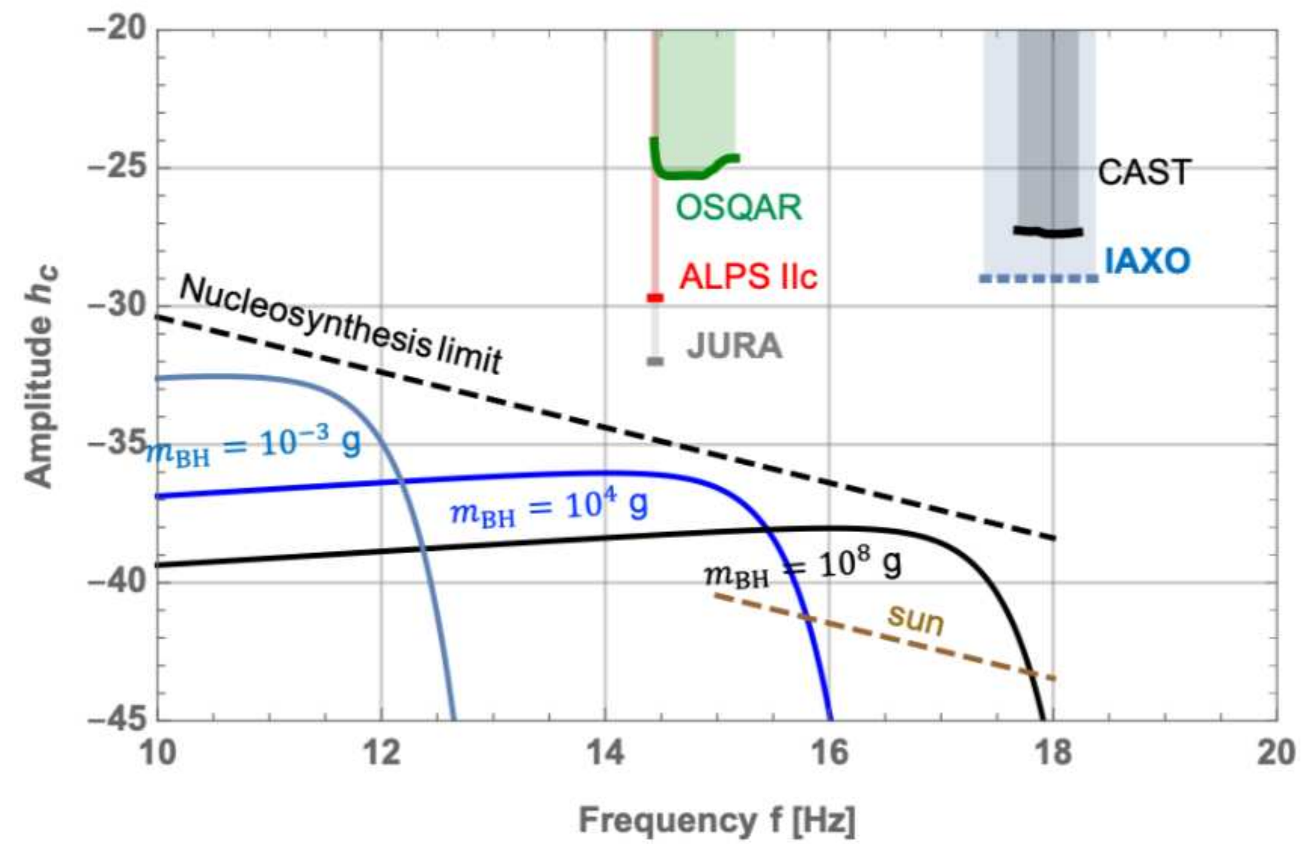


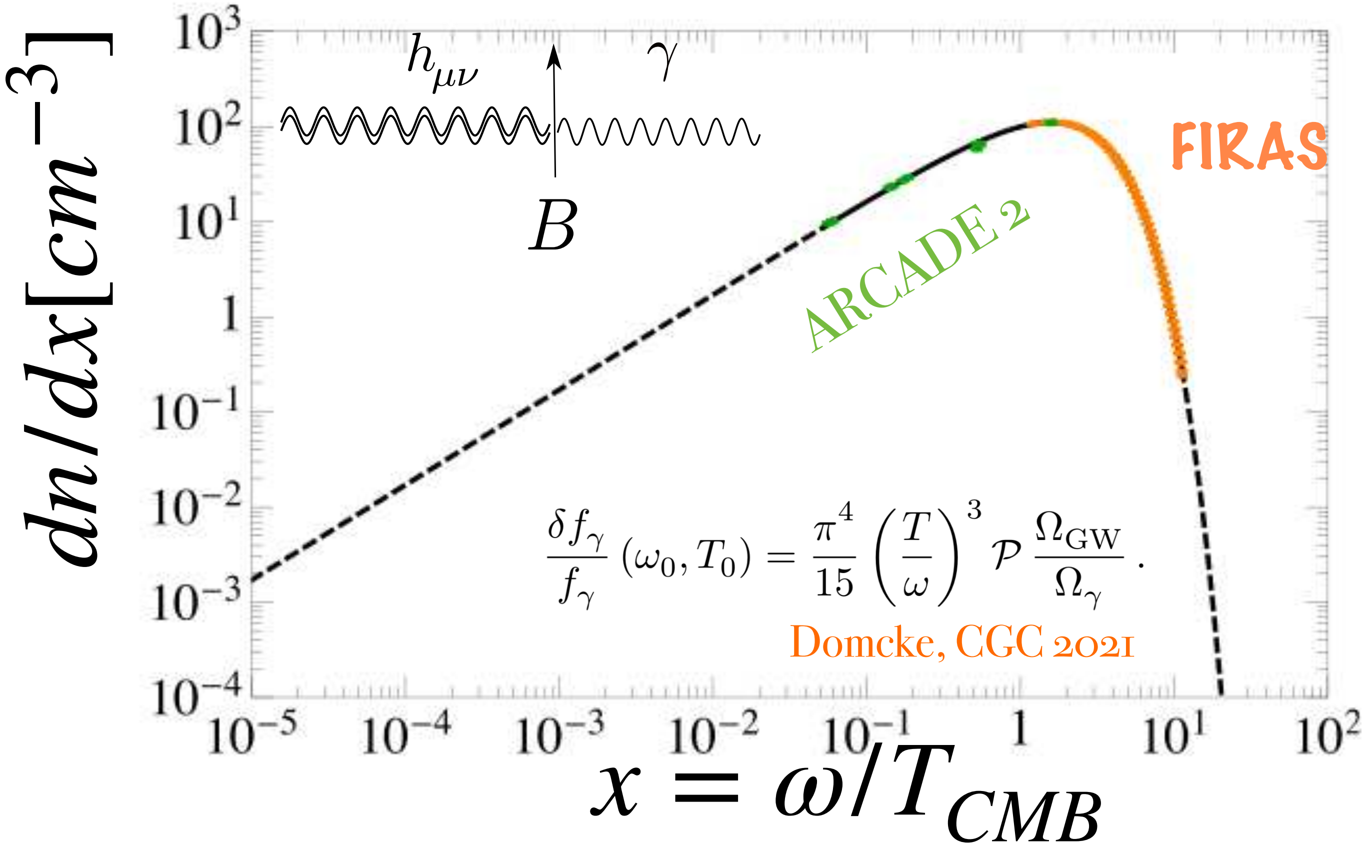
Upper limits on the amplitude of ultra-high-frequency gravitational waves from graviton to photon conversion

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

The European Physical Journal C **79**, Article number: 1032 (2019) | Cite this article



Cosmological Detectors



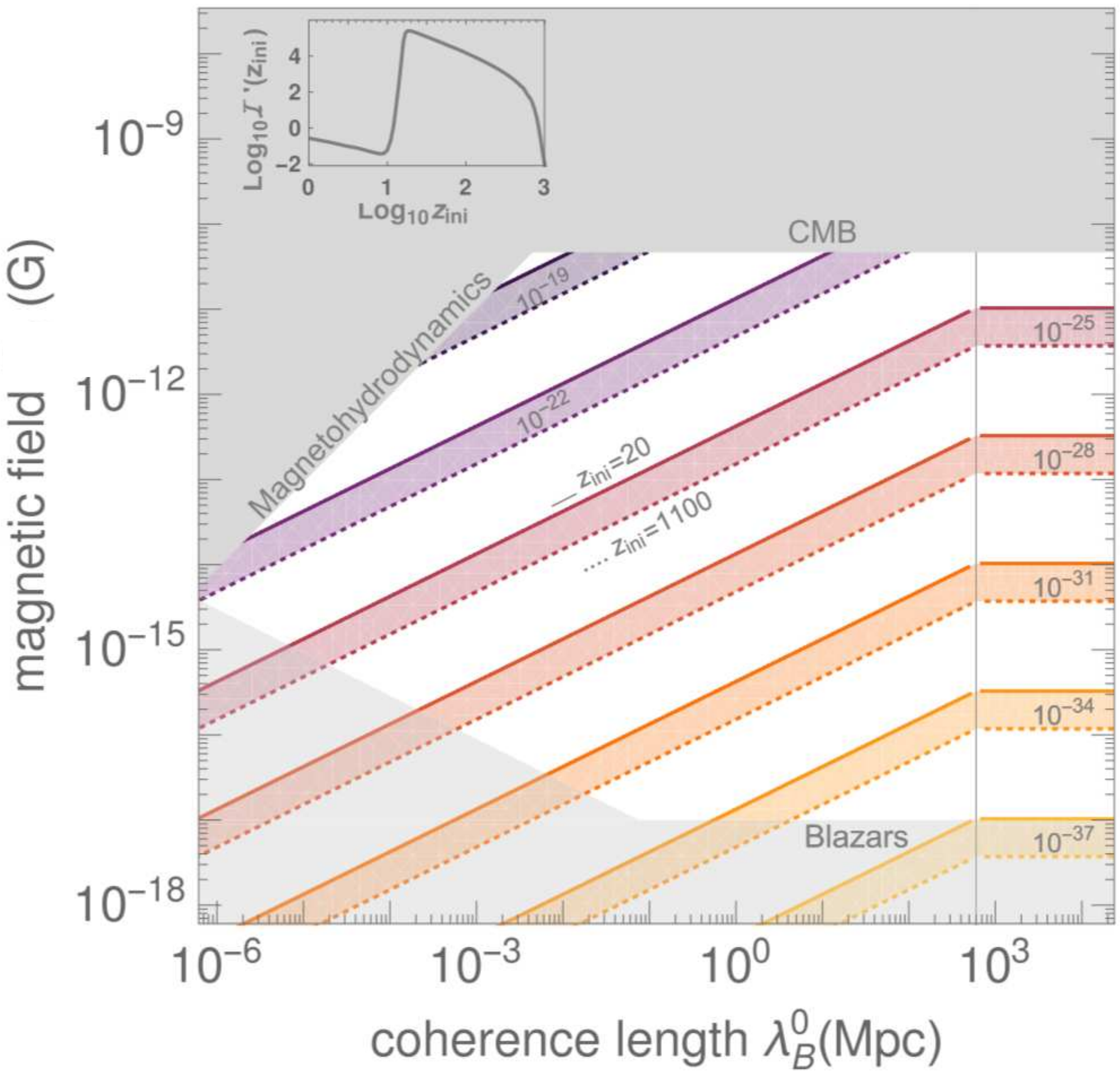
- Involving gravity the conversion probabilities are extremely small. It may be compensated by a 'detector' of cosmological size
- RJ tail remains unexplored with upcoming advances in radio astronomy probing it in the near future.

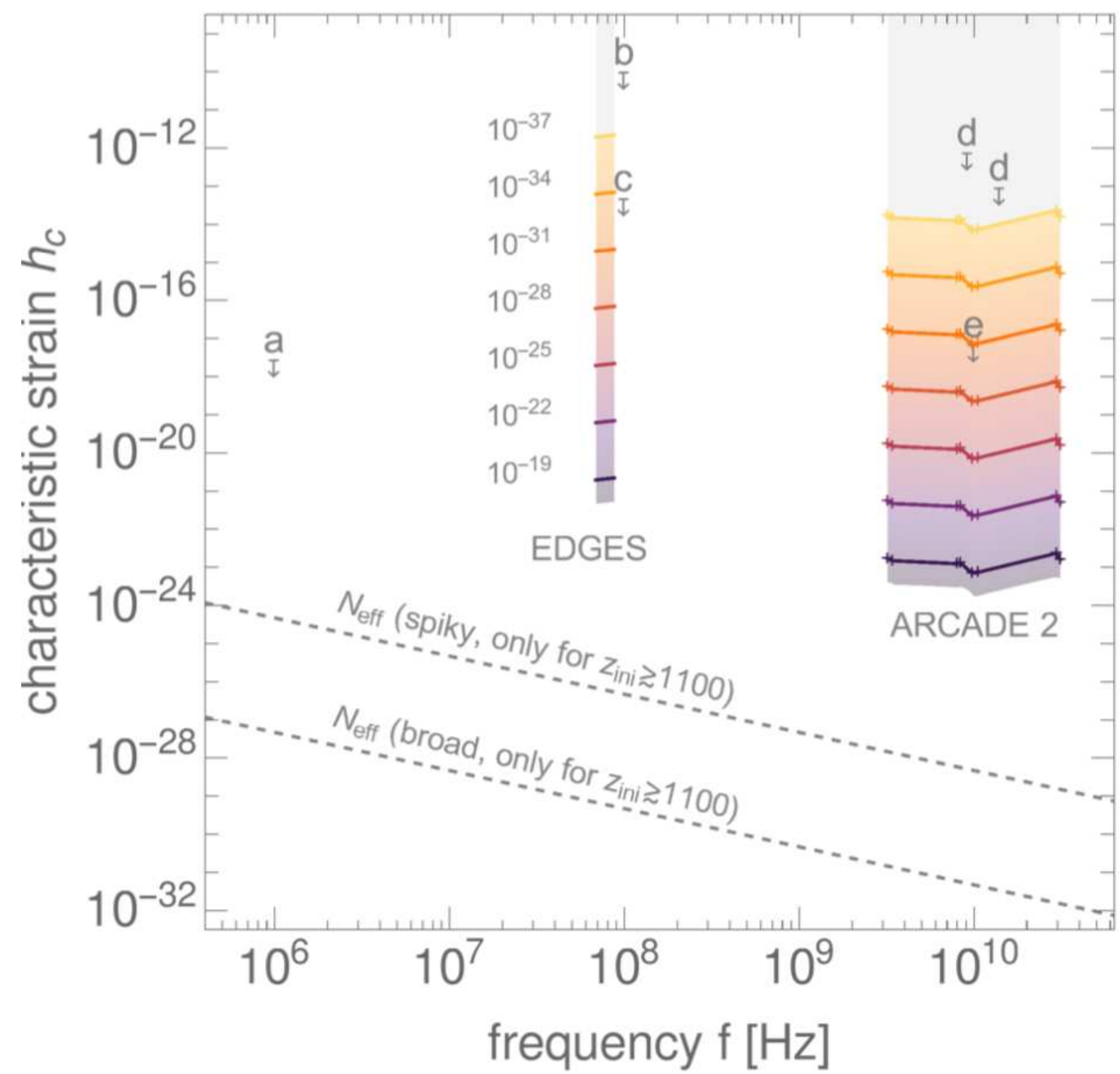
Cosmological Detectors

PHYSICAL REVIEW LETTERS **126,** 021104 (2021)

Potential of Radio Telescopes as High-Frequency Gravitational Wave Detectors

Valerie Domcke[1,2,3,*] and Camilo Garcia-Cely[1,†]





existing laboratory bounds from

a) superconducting parametric converter Reece et al '84

b) waveguide Cruise Ingley '06

c) 0.75 m interferometer Akutsu '08

d) magnon detector Ito, Soda '04

e) magnetic conversion detector Cruise et al '12

Not everything is axion photon conversion

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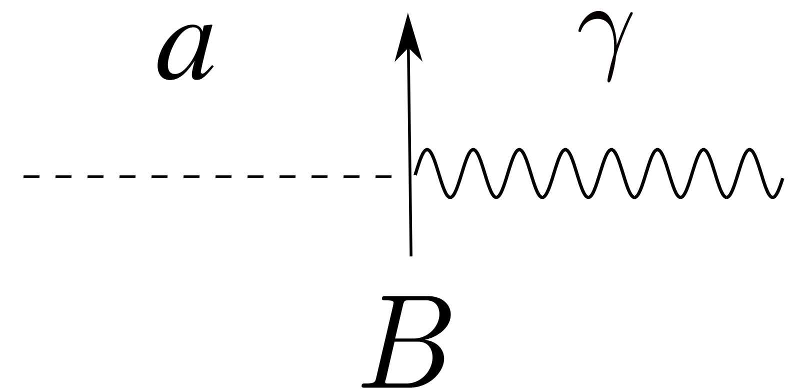

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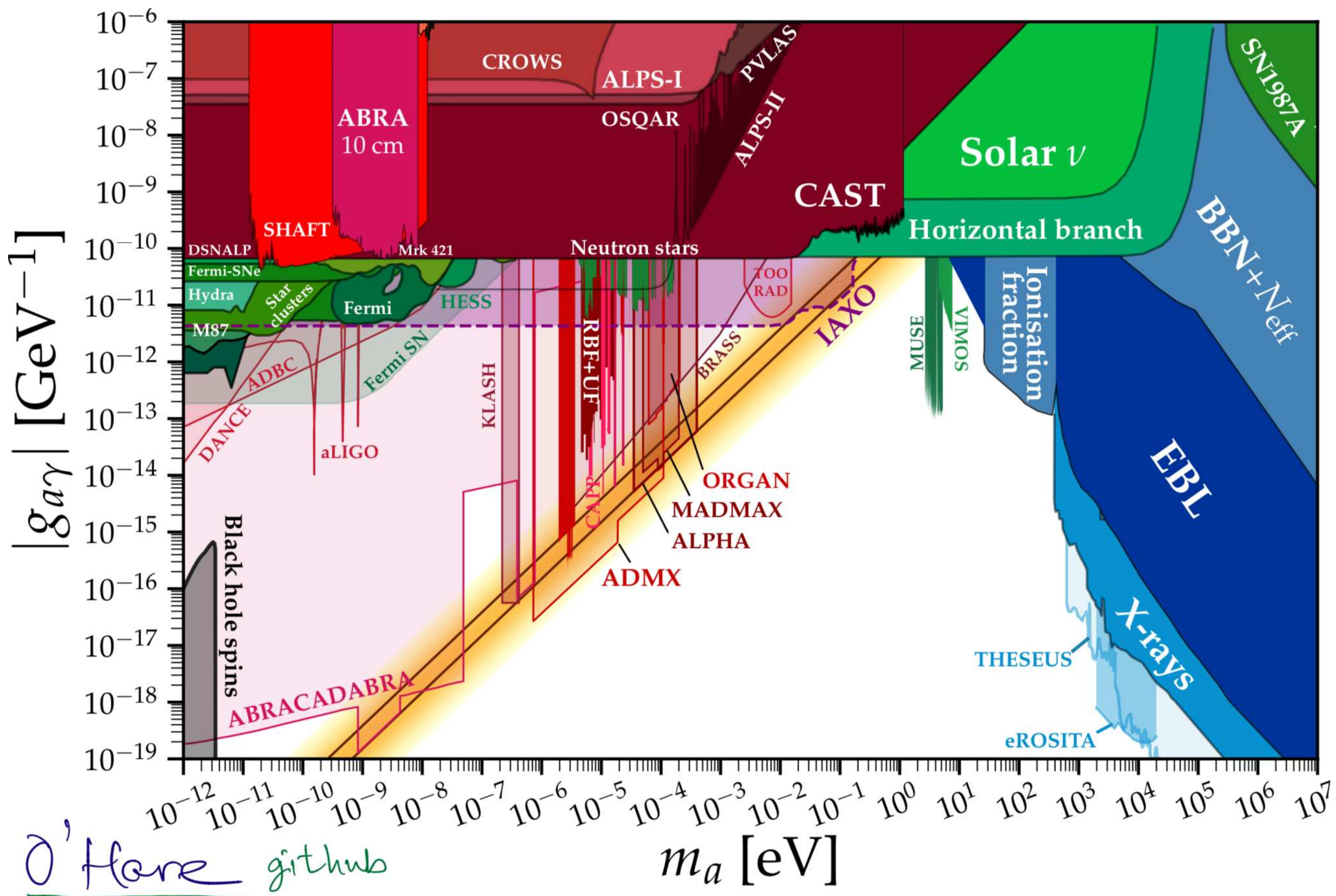

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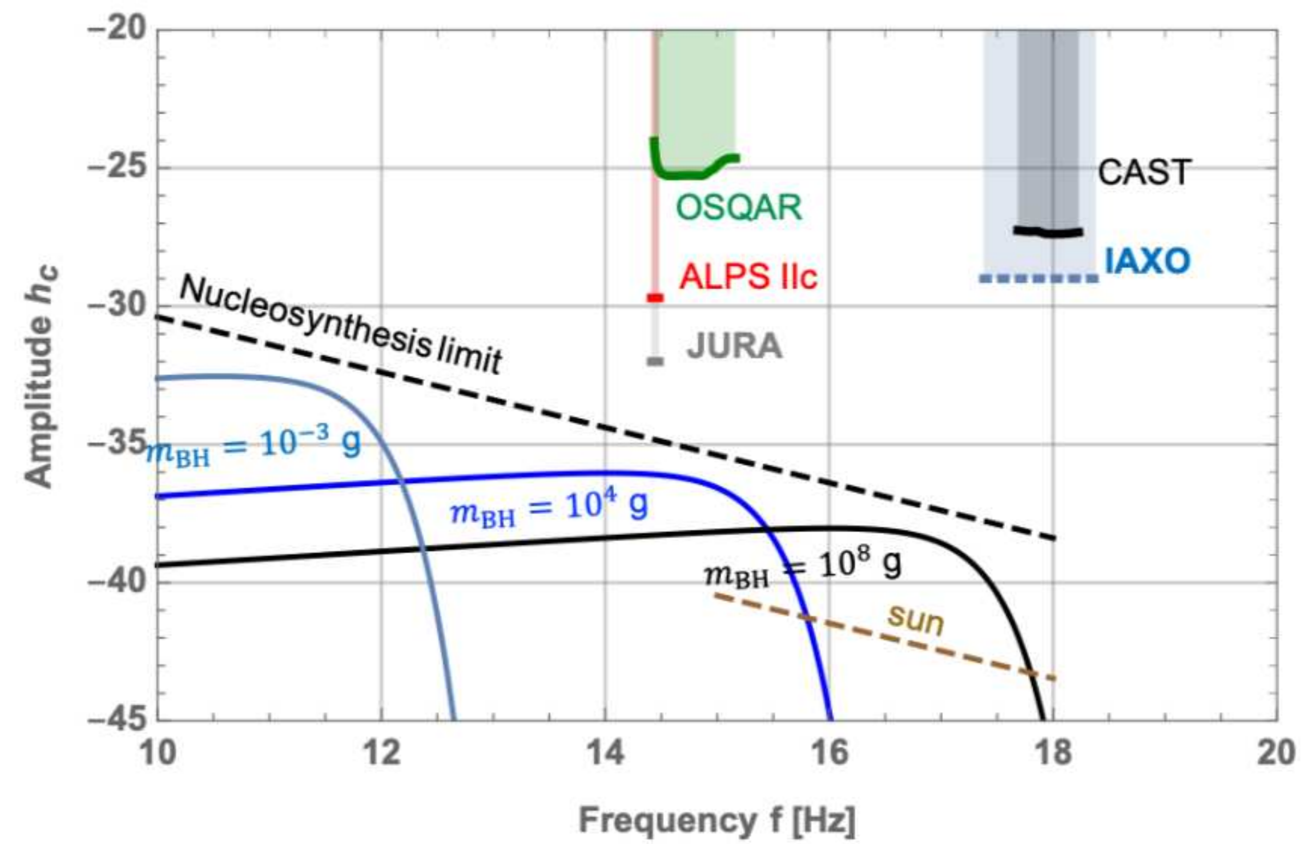

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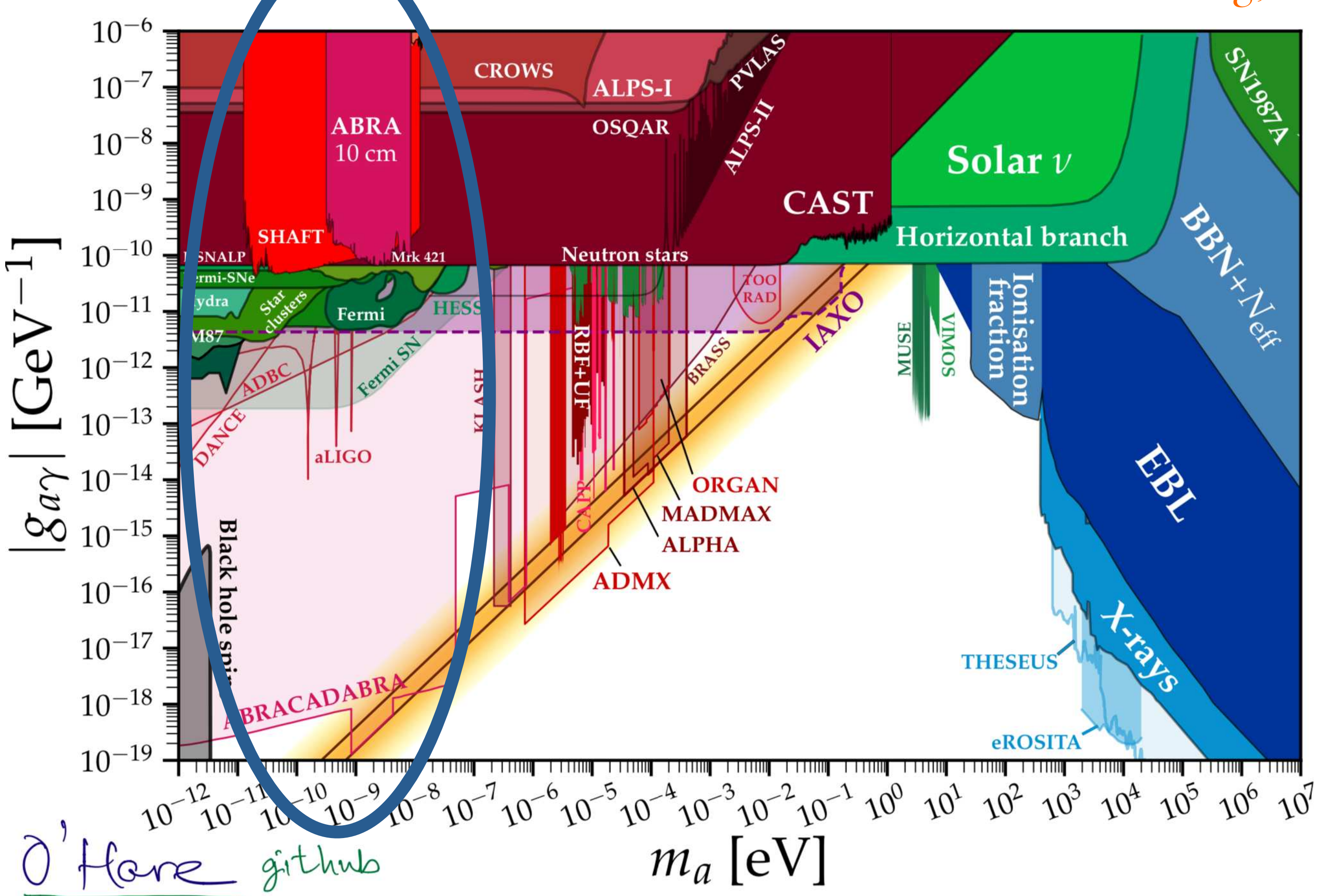
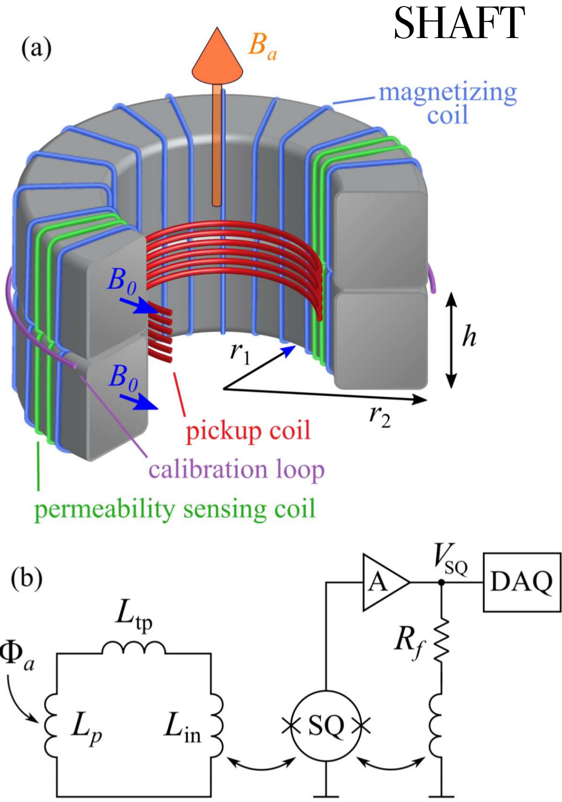


O'Hare github

haloscopes based on lumped-element detectors



Axion electrodynamics

In the presence of an external electromagnetic field, axions act as a source term to Maxwell′s equations, effectively inducing an electromagnetic current.

$$\partial_\nu F^{\mu\nu} = j^\mu_{\text{eff}}$$

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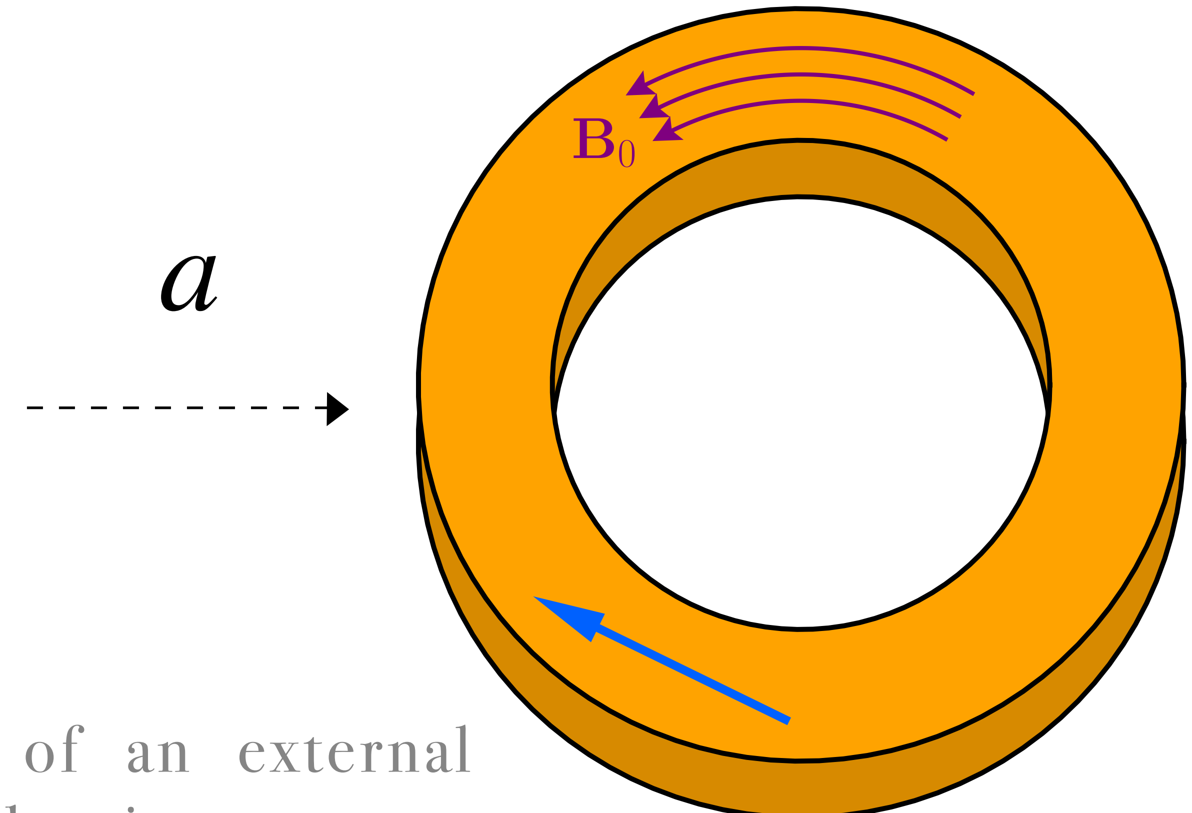

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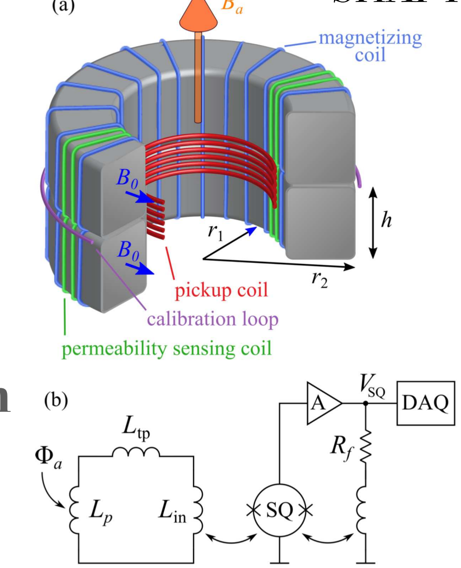

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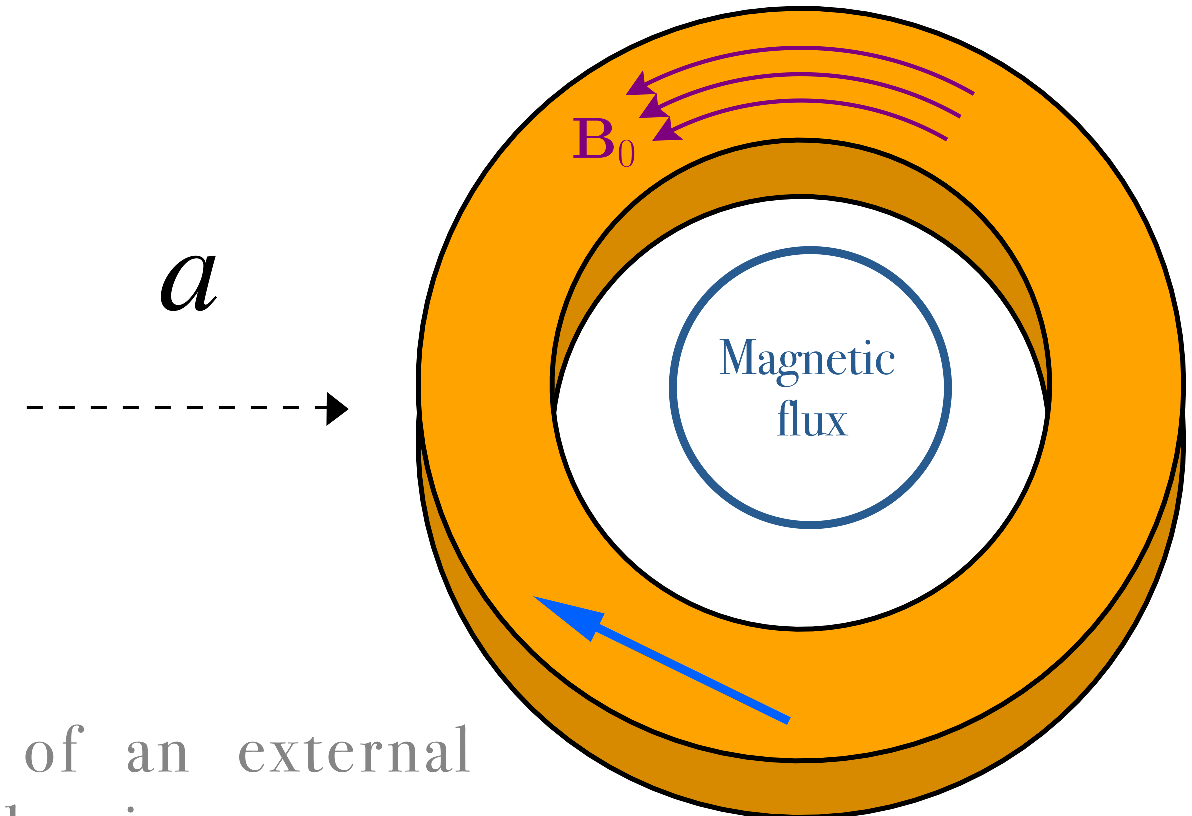

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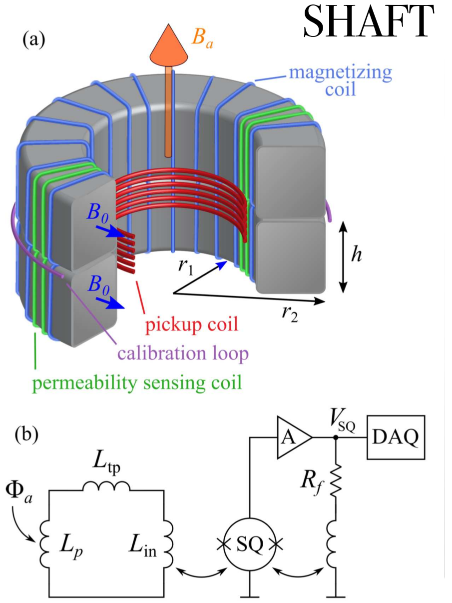

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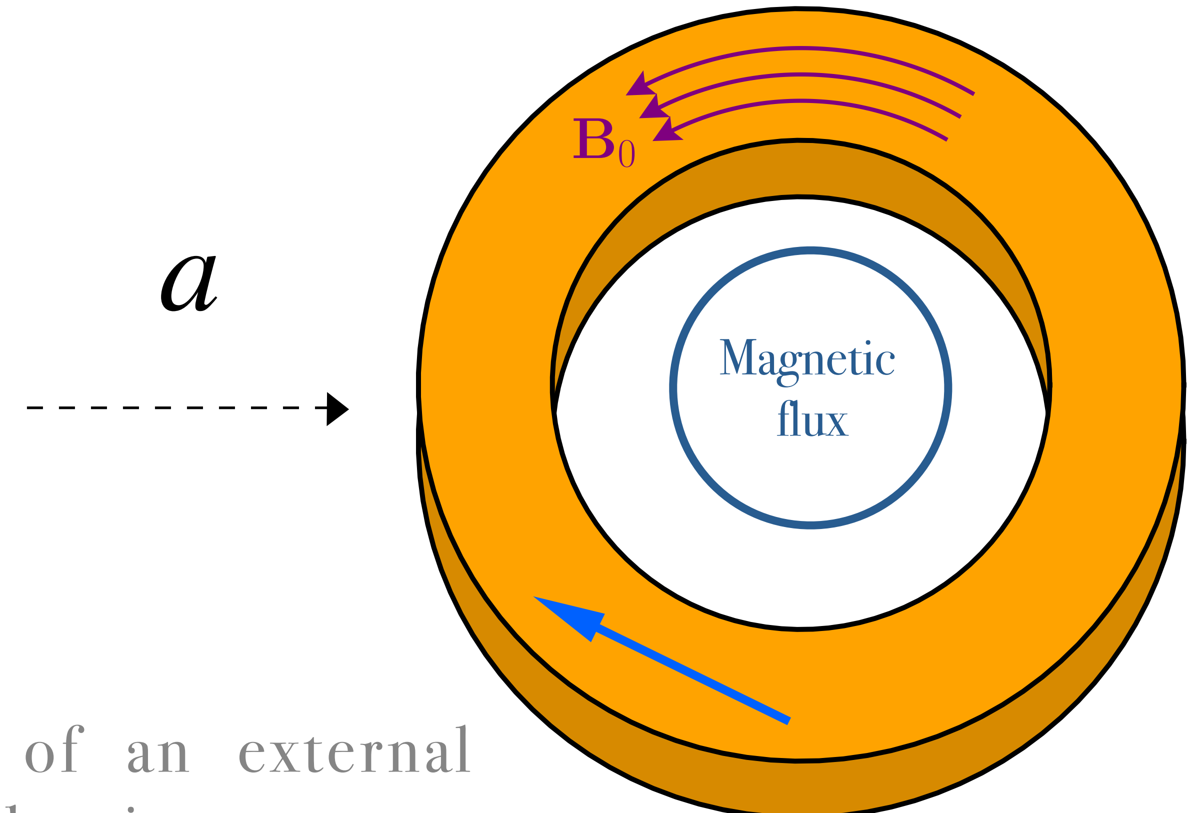

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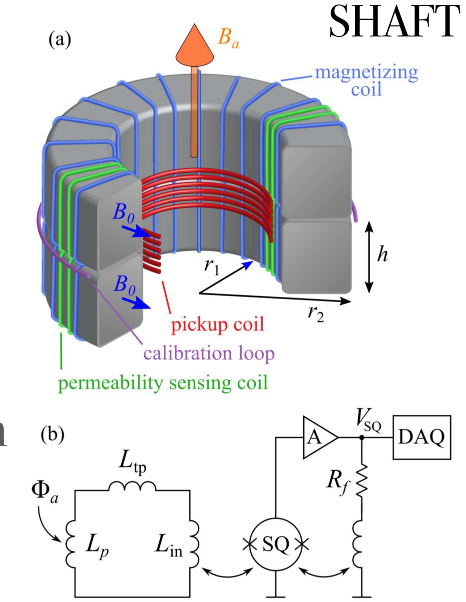

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$$P_i = g_{a\gamma\gamma} a B_i$$

$$M_i = g_{a\gamma\gamma} a E_i$$

McAllister et al, 1803.07755
Tobar et al, 1809.01654
Ouellet et al, 1809.10709

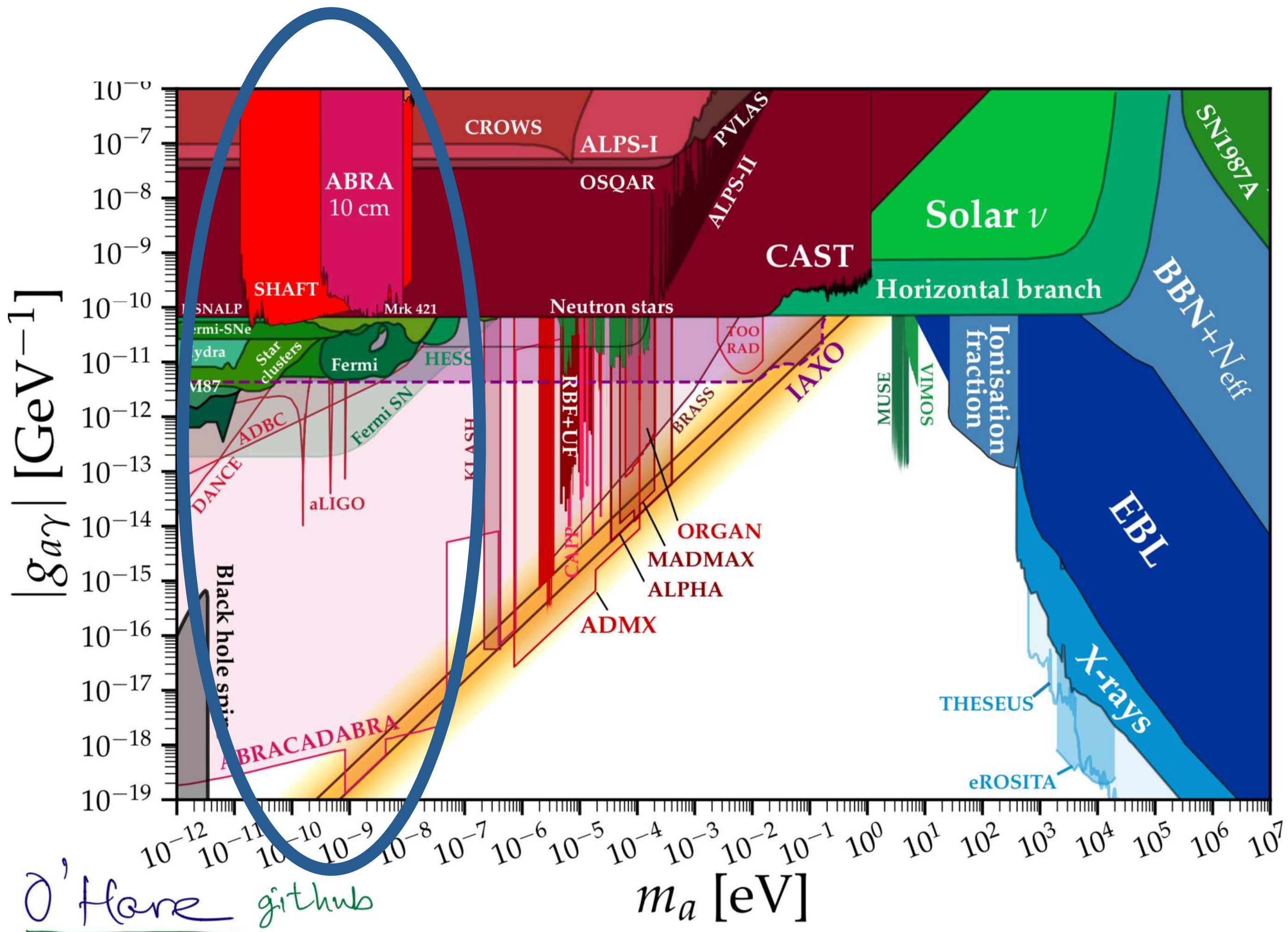
GW electrodynamics

A novel search for high-frequency gravitational waves with low-mass axion haloscopes

Valerie Domcke,[1,2] Camilo Garcia-Cely,[3] and Nicholas L. Rodd[1]

[1] *Theoretical Physics Department, CERN, 1 Esplanade des Particules, CH-1211 Geneva 23, Switzerland*
[2] *Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland*
[3] *Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany*

Gravitational waves (GWs) generate oscillating electromagnetic effects in the vicinity of external electric and magnetic fields. We discuss this phenomenon with a particular focus on reinterpreting the results of axion haloscopes based on lumped-element detectors, which probe GWs in the 100 kHz - 100 MHz range. Measurements from ABRACADABRA and SHAFT already place bounds on GWs, although the present strain sensitivity is weak. However, we demonstrate that the sensitivity scaling with the volume of such instruments is significant – faster than for axions – and so rapid progress will be made in the future. With no modifications, DMRadio-m^3 will have a GW strain sensitivity of $h \sim 10^{-20}$ at 200 MHz. A simple modification of the pickup loop used to readout the induced magnetic flux can parametrically enhance the GW sensitivity, particularly at lower frequencies.



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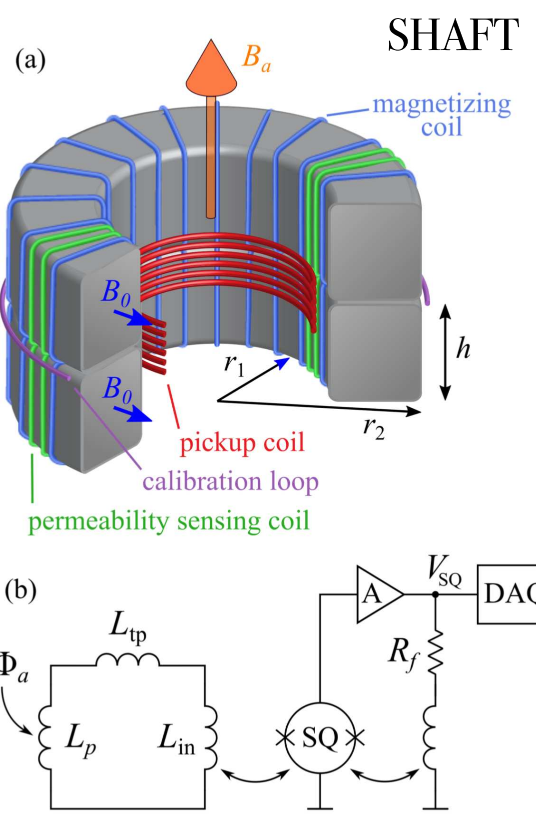

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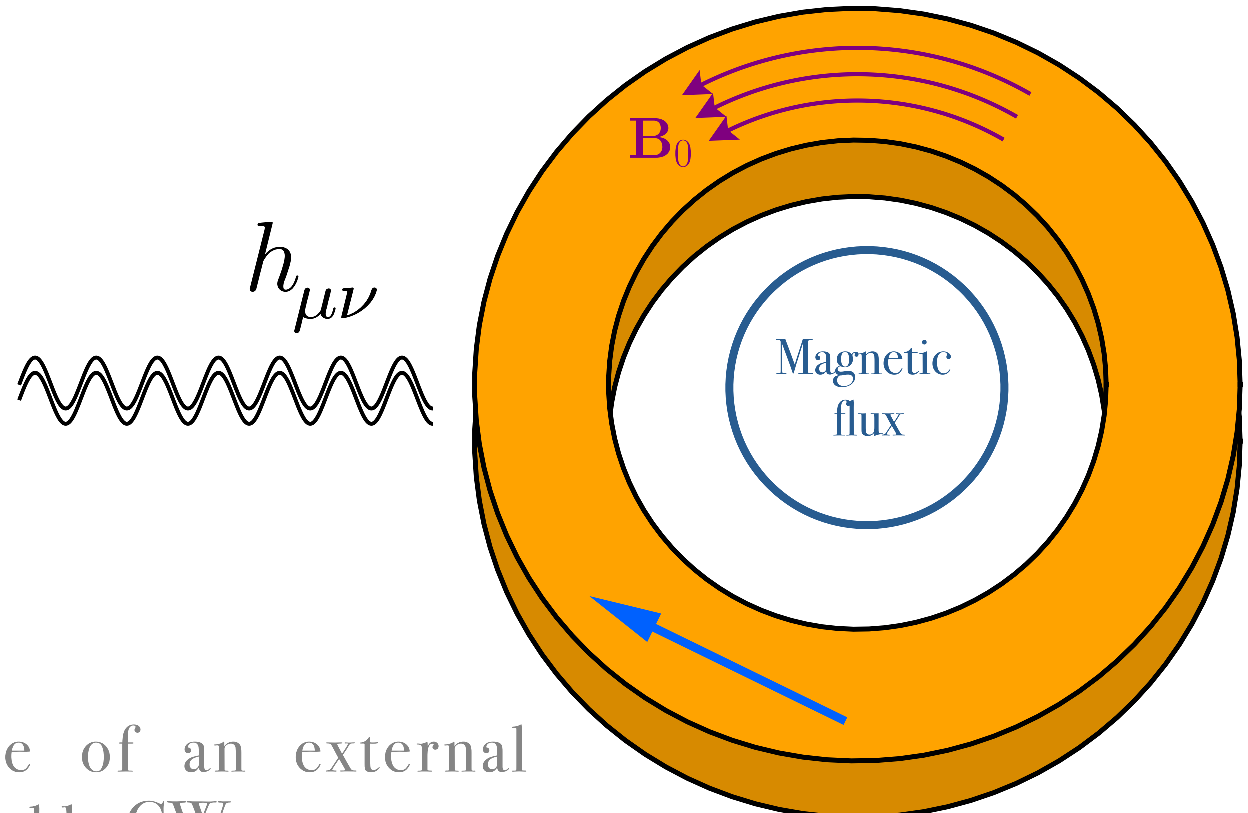

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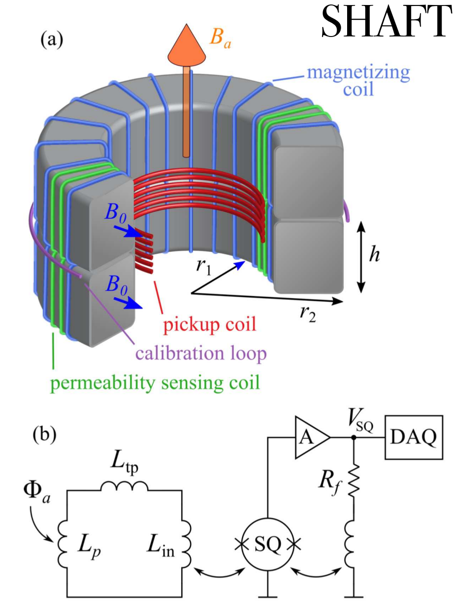

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Domcke, CGC, Rodd, 2202.00695

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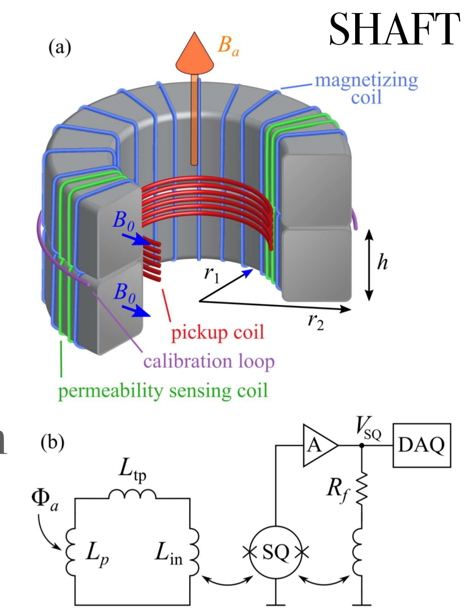

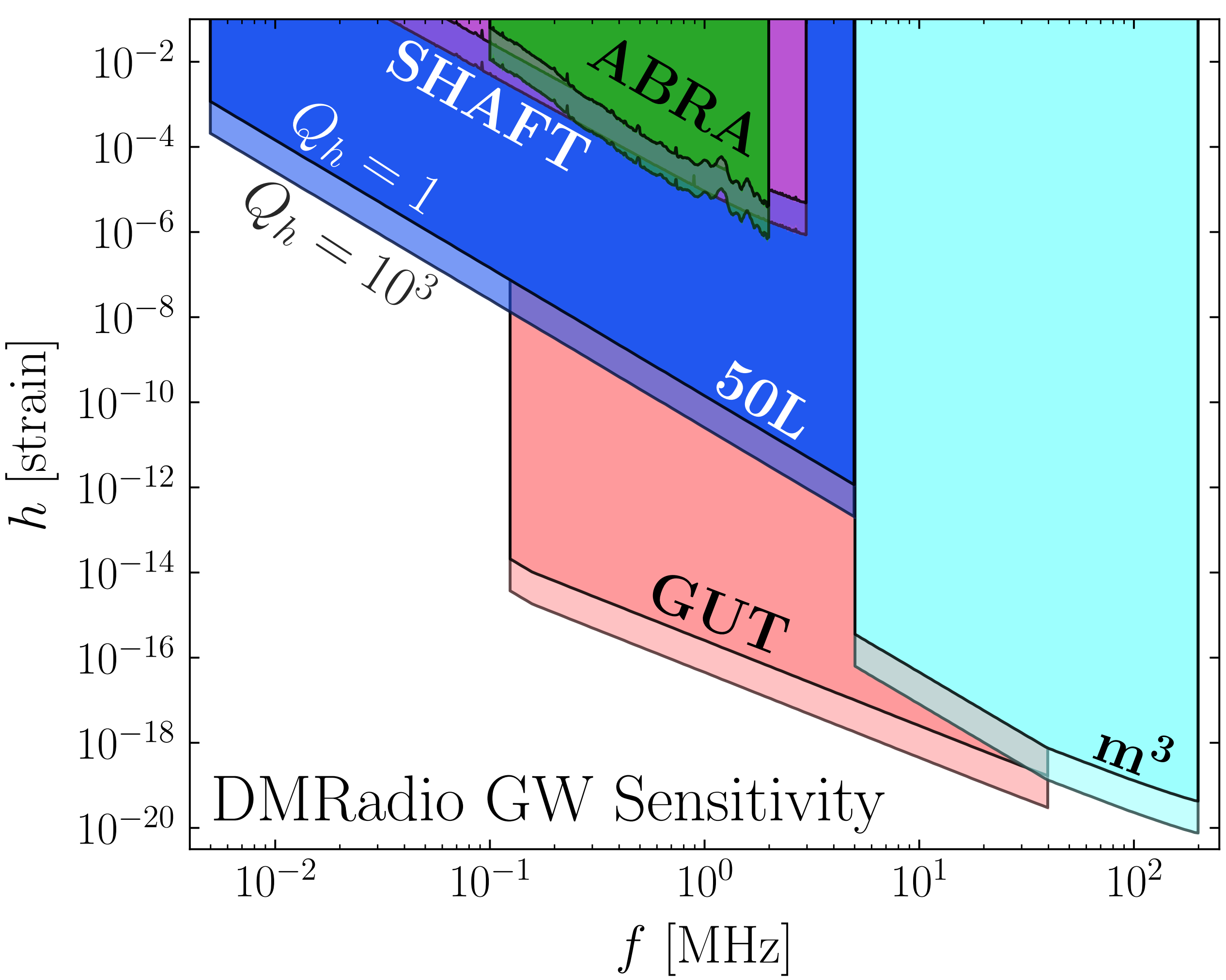

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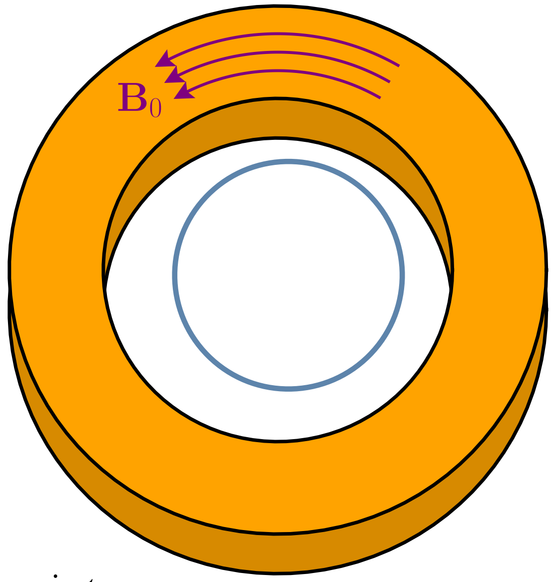
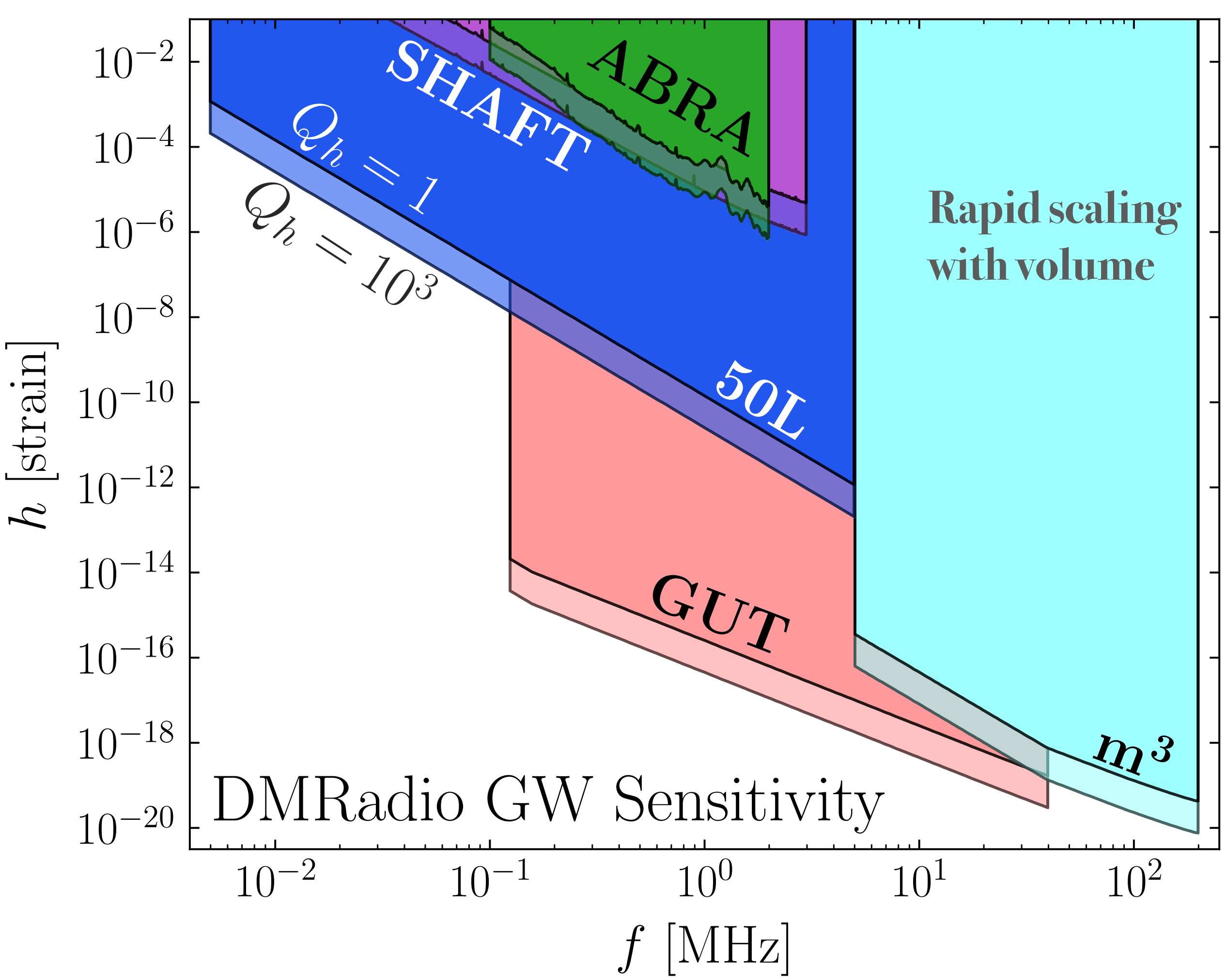
Highly symmetric: one polarisation mode decouples and suppression at $\omega R \ll 1$



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



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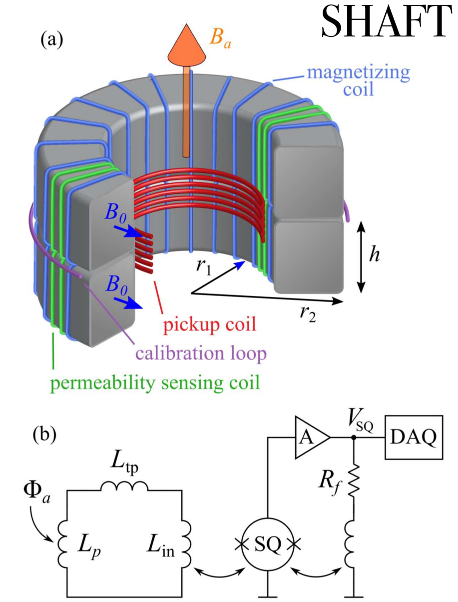

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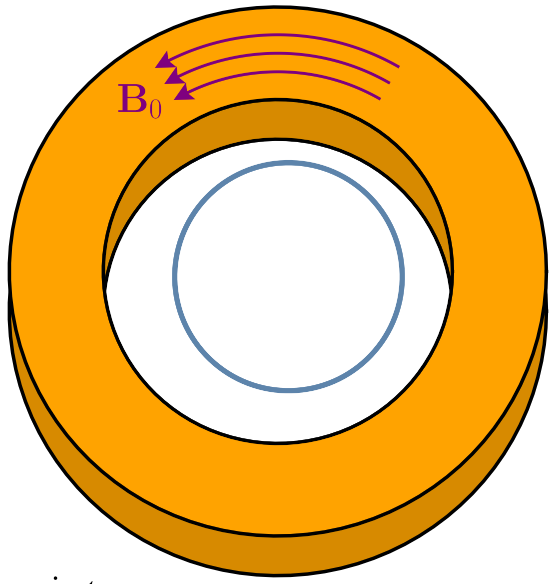

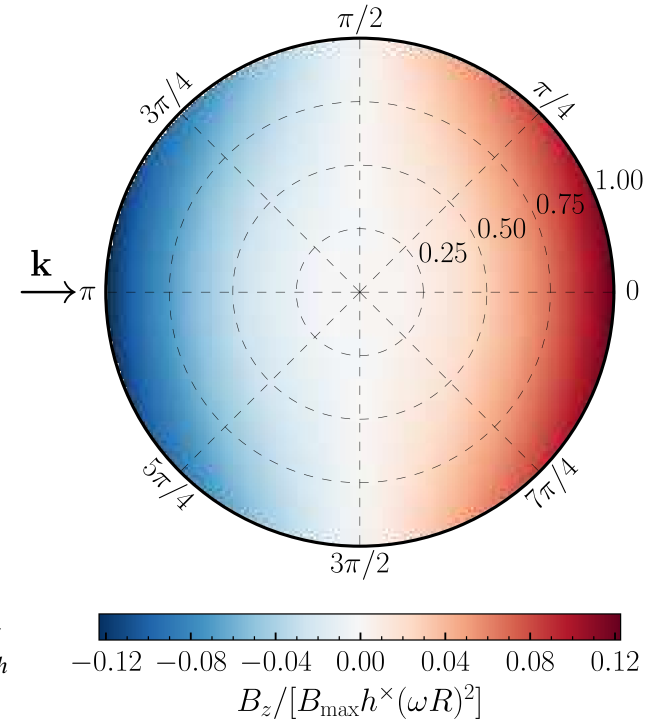

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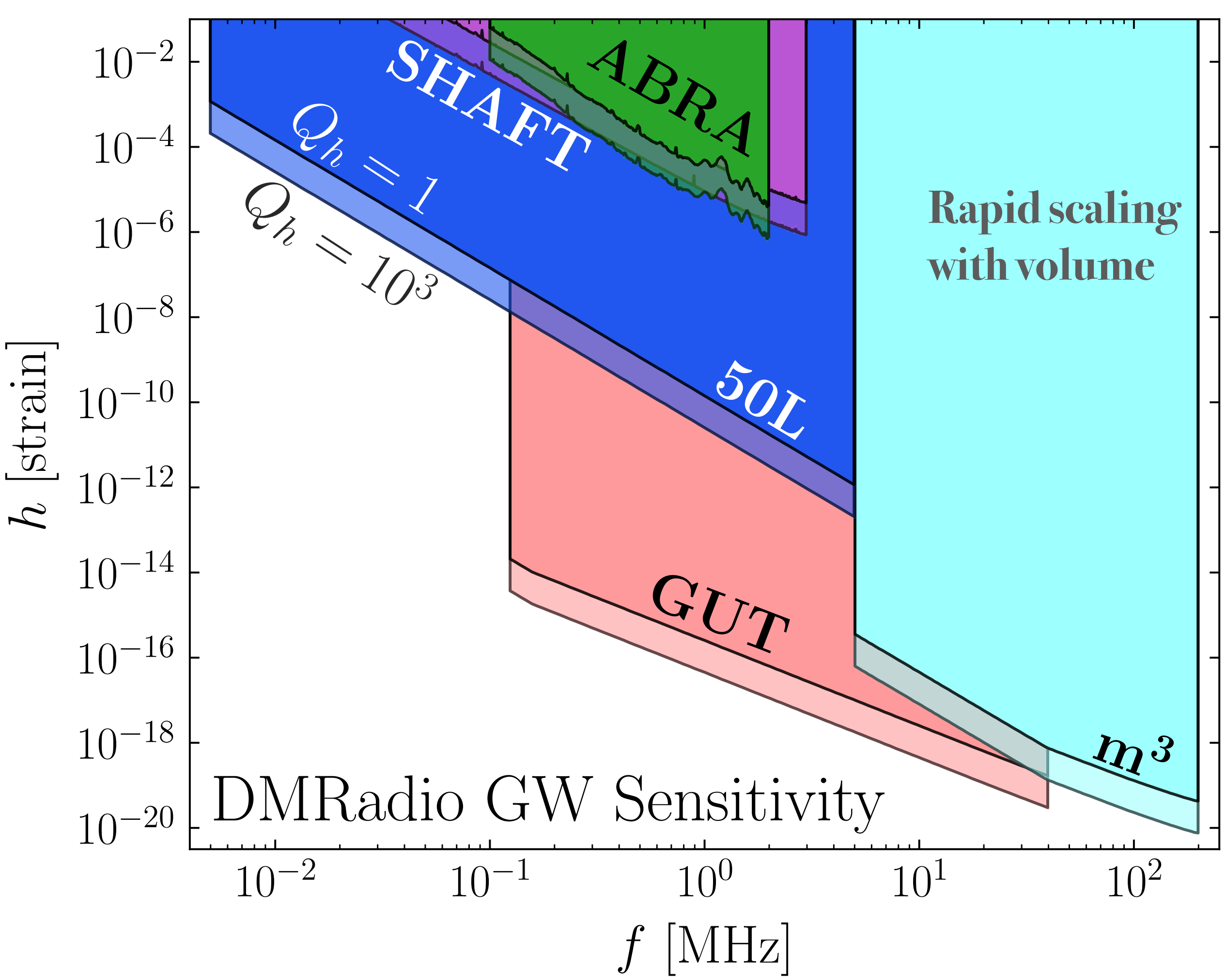

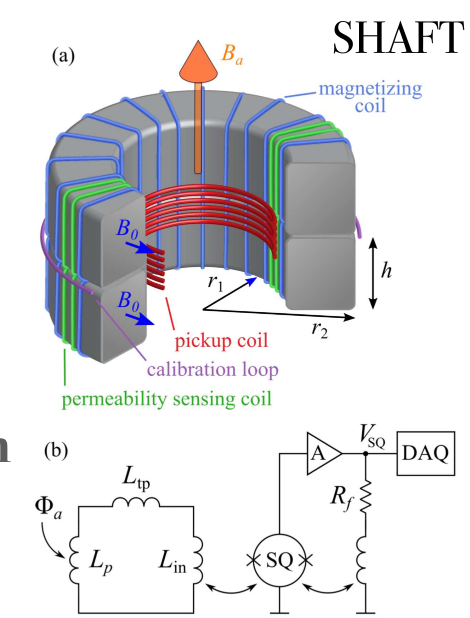

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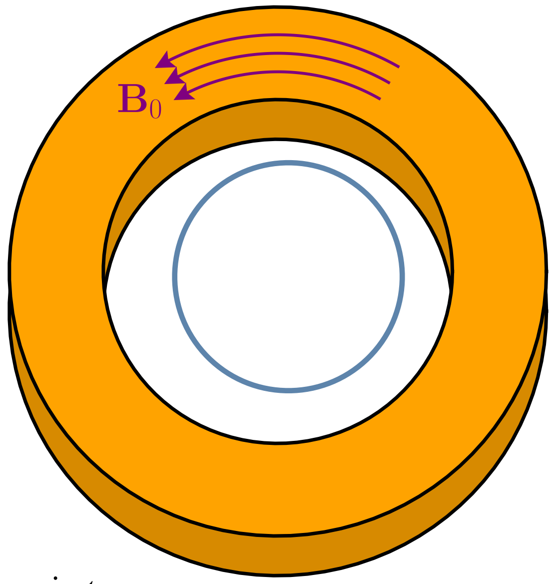

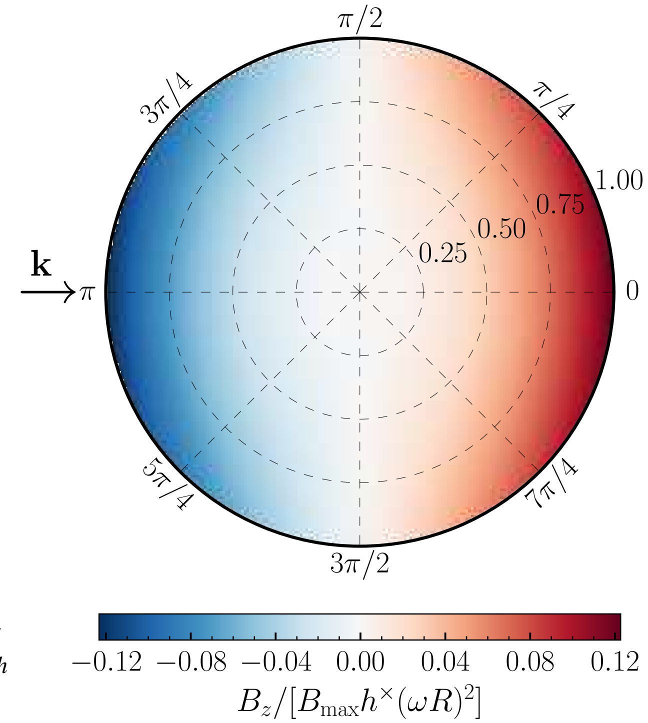

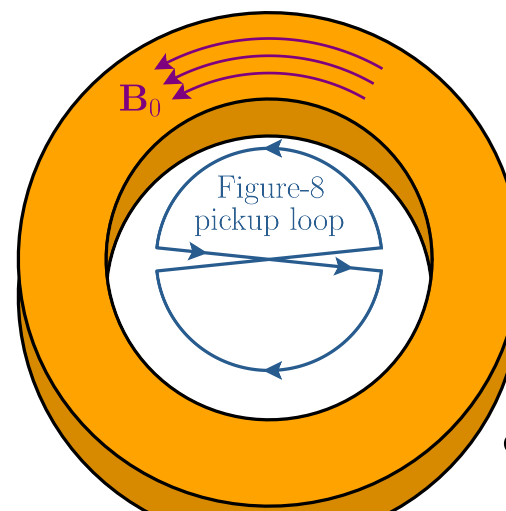

$$\Phi_8 = \frac{e^{-i\omega t}}{3\sqrt{2}} \omega^2 B_{\max} r^3 R \ln(1 + a/R) s_{\theta_h} \times \left(h^\times s_{\phi_h} - h^+ c_{\theta_h} c_{\phi_h} \right).$$

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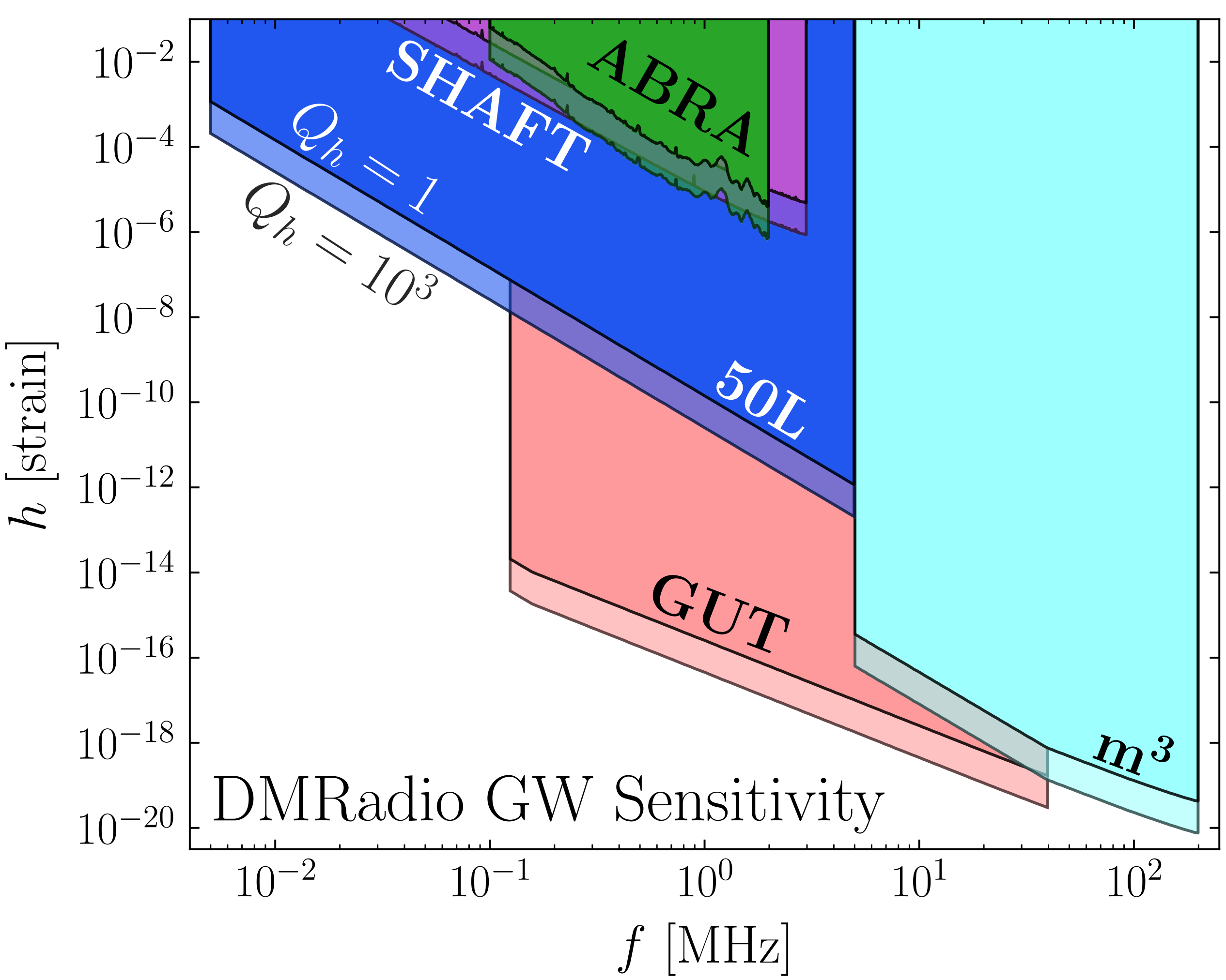

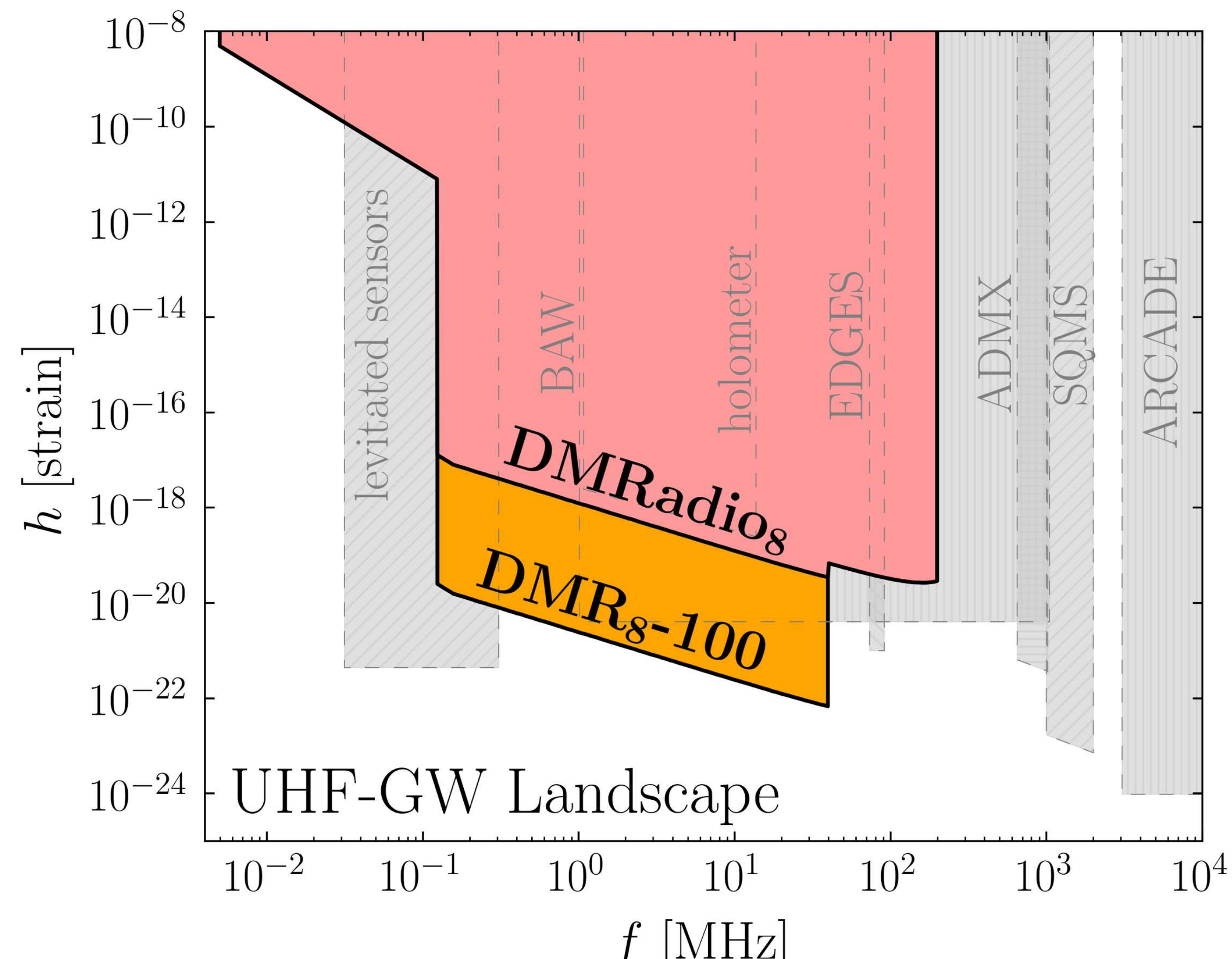

GW electrodynamics

Detecting High-Frequency Gravitational Waves with Microwave Cavities

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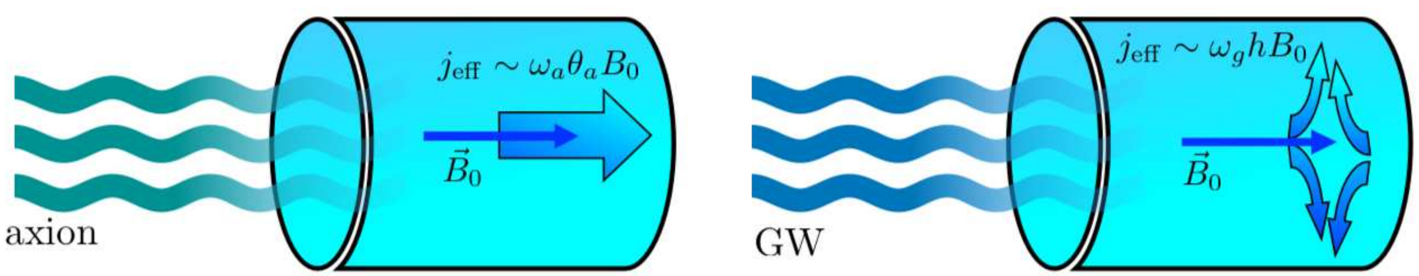

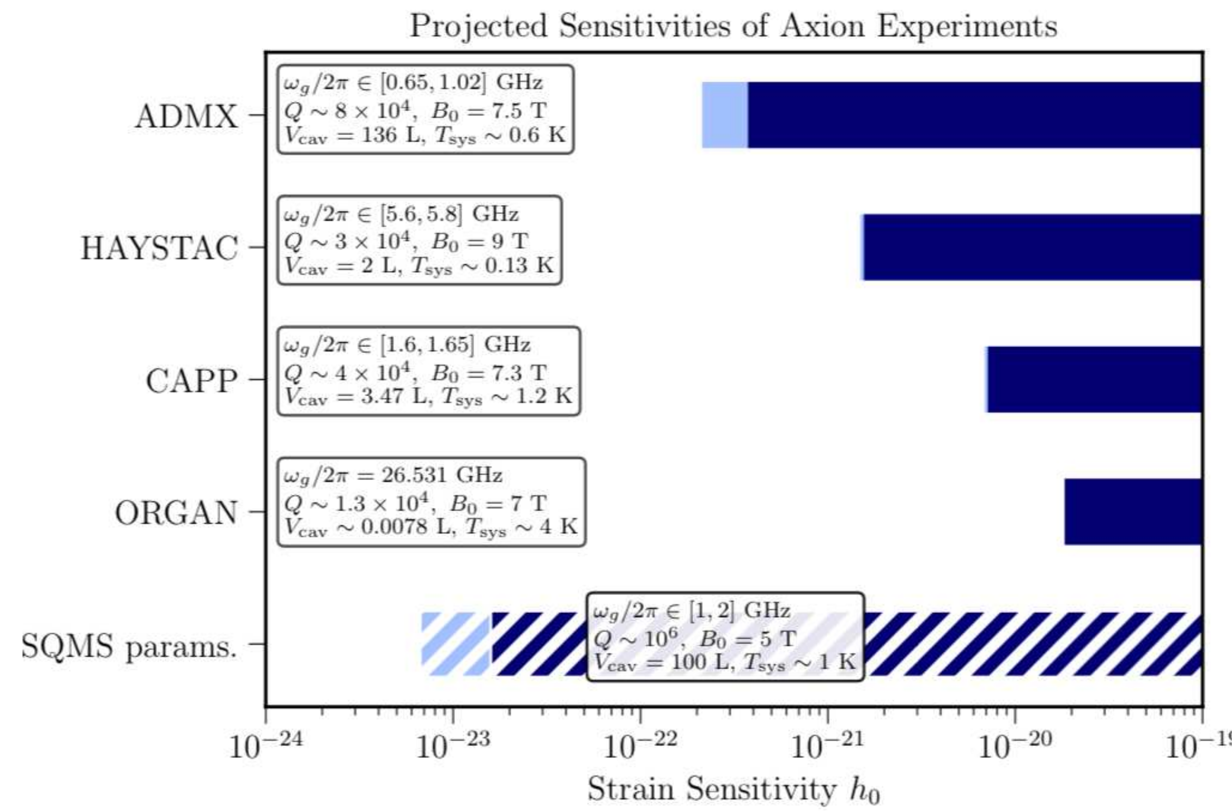

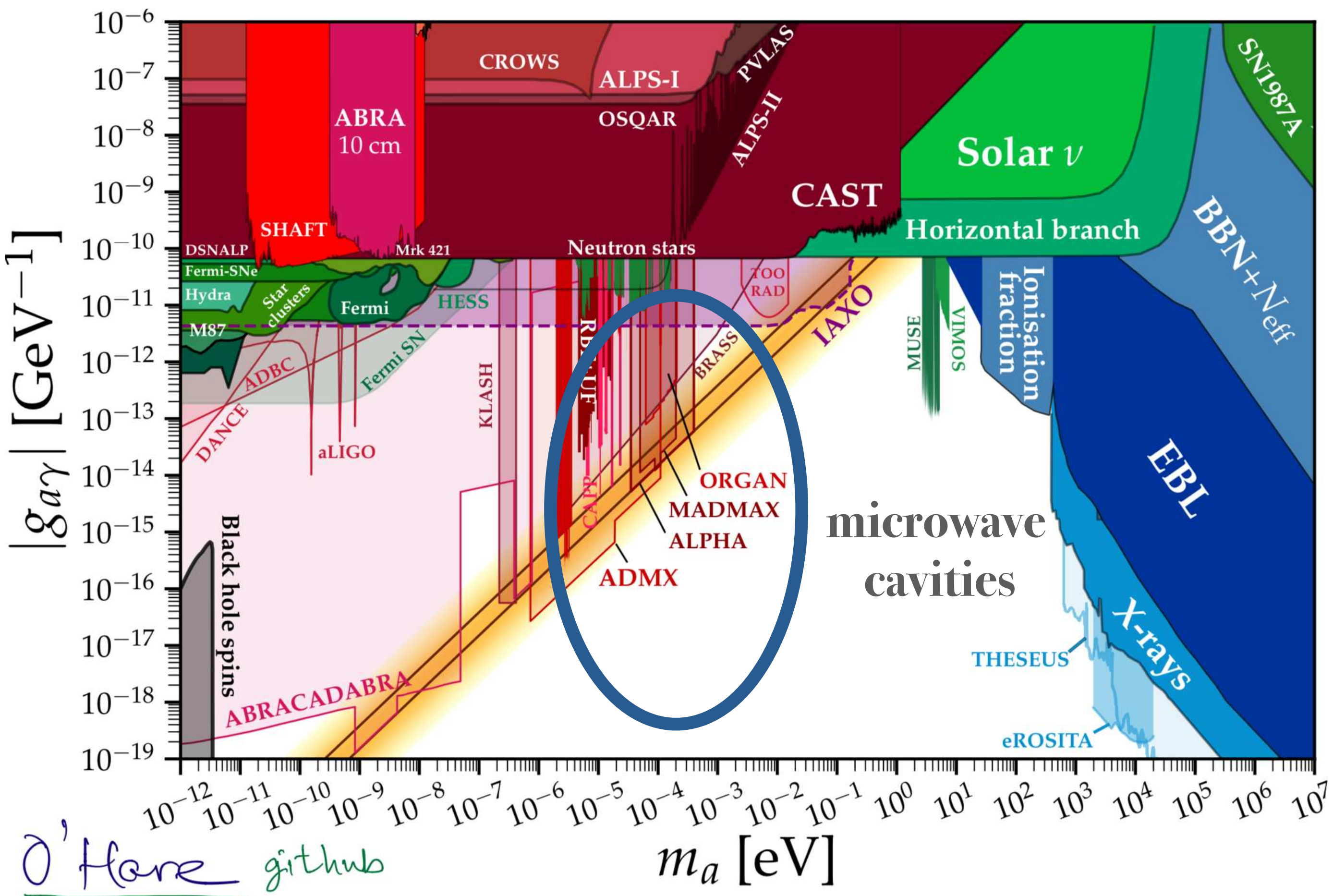

O'Hare github

GW electrodynamics

In the presence of an external electromagnetic field, GWs act as a source term to Maxwell′s equations, effectively inducing an electromagnetic current.

$$\partial_\nu F^{\mu\nu} = j^\mu_{\text{eff}}$$

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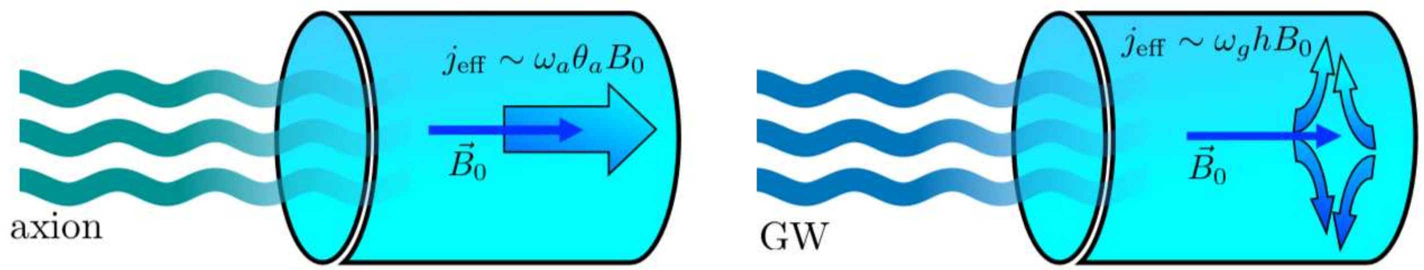

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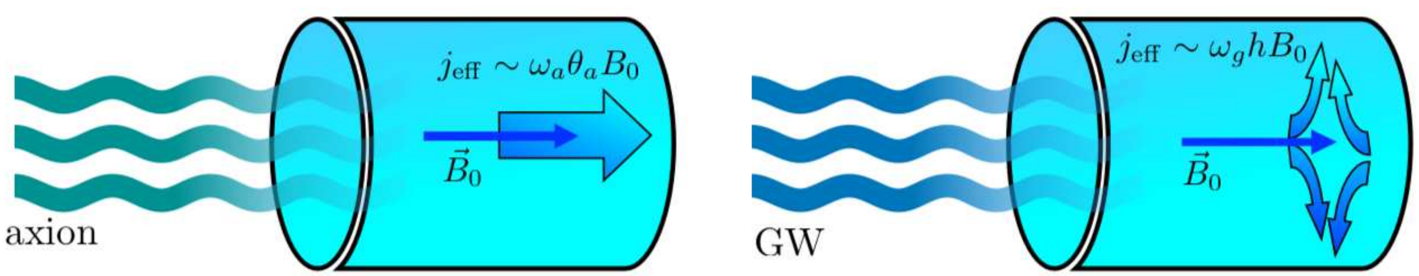

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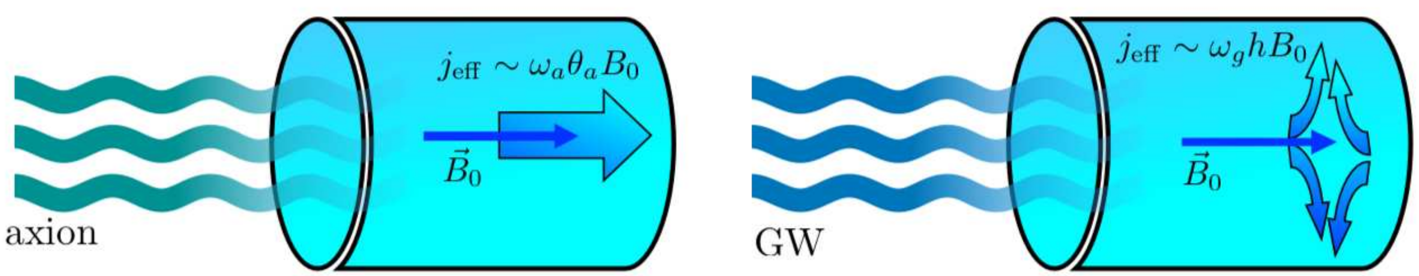

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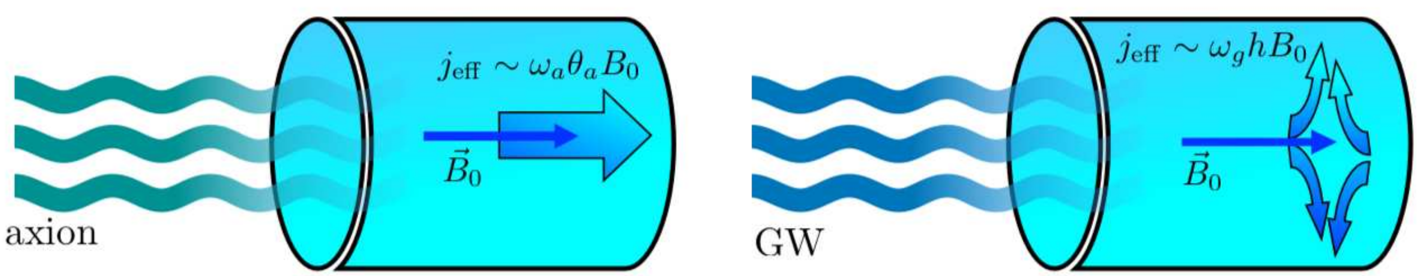

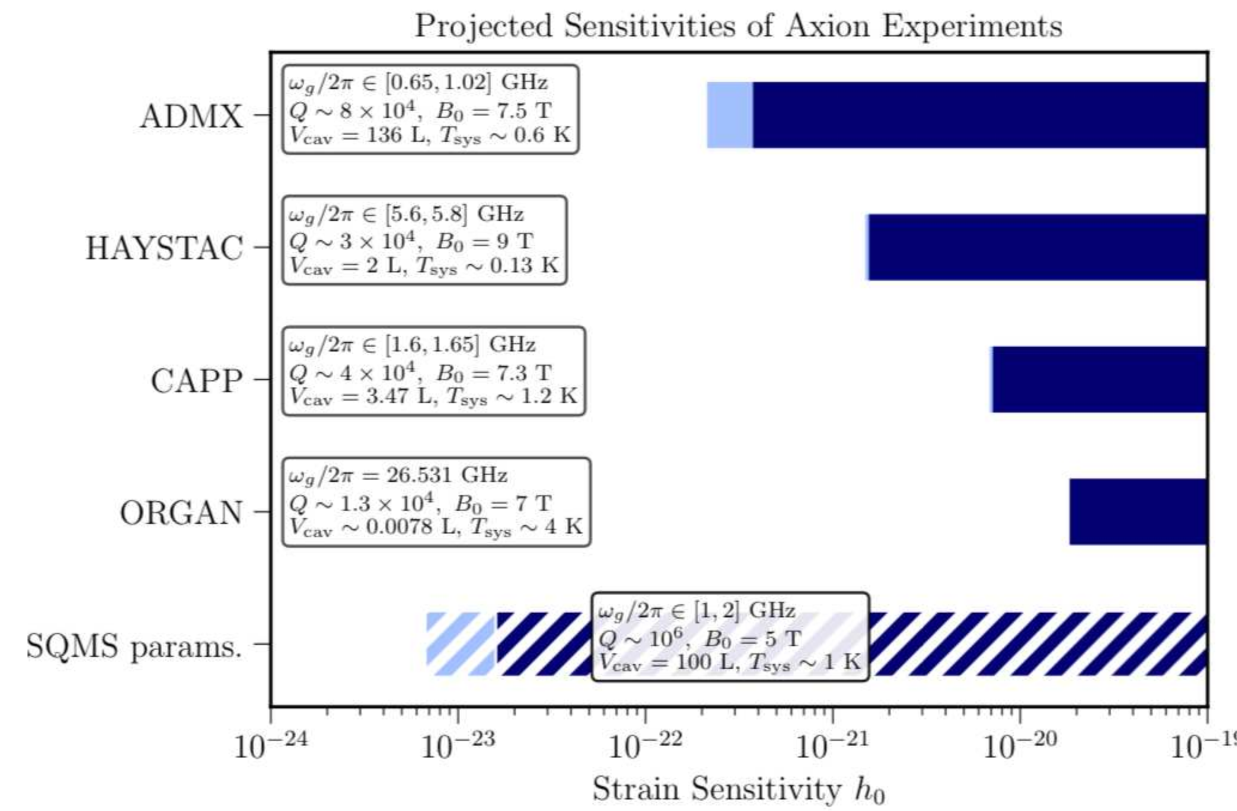

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It resonates when the GW frequency matches one of the eigenmode frequencies

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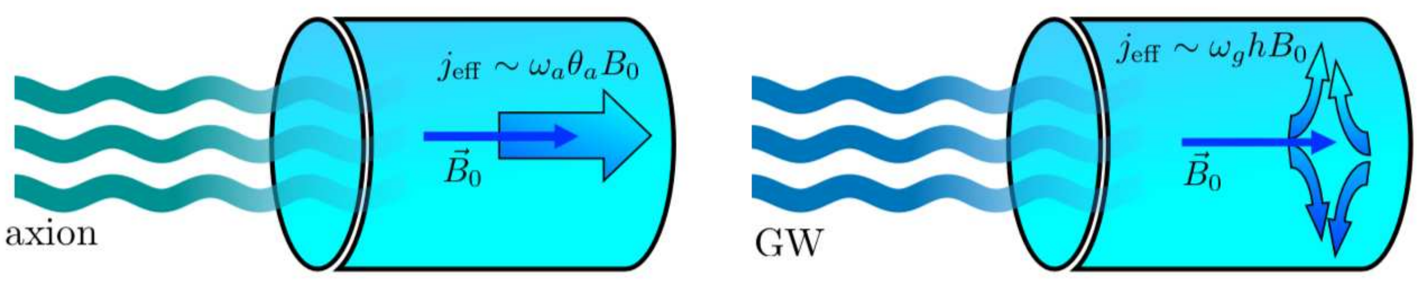

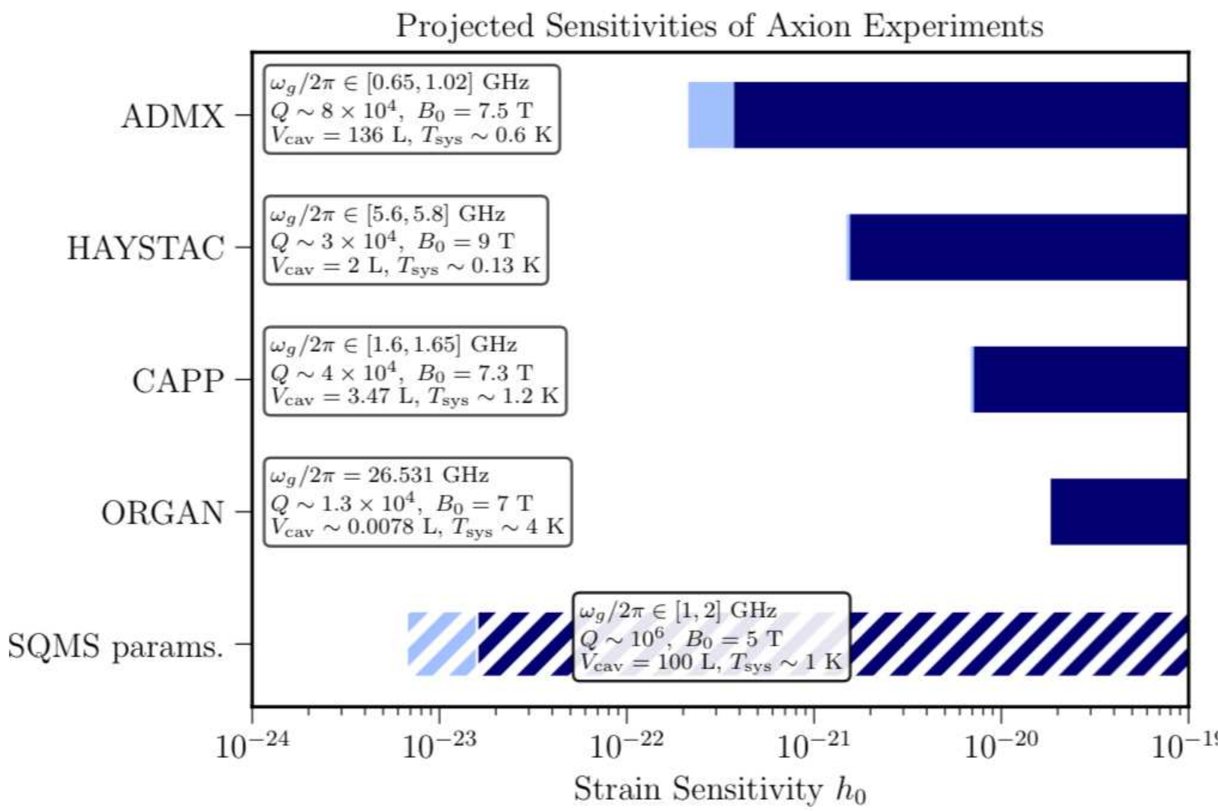

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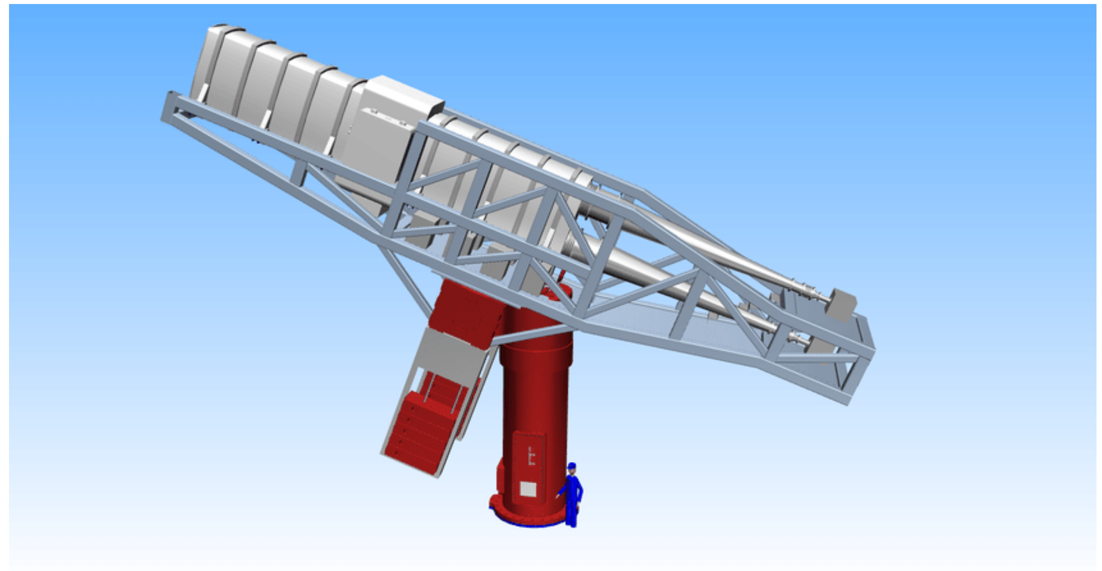
Subtleties due to gauge fixing (TT vs detector frame gauge)

(Baby)IAXO



Design of New Resonant Haloscopes in the Search for the Dark Matter Axion: A Review of the First Steps in the RADES Collaboration

by Alejandro Díaz-Morcillo [1,*], José María García Barceló [1], Antonio José Lozano Guerrero [1], Pablo Navarro [1], Benito Gimeno [2], Sergio Arguedas Cuendis [3], Alejandro Álvarez Melcón [1], Cristian Cogollos [4], Sergio Calatroni [3], Babette Döbrich [3], Juan Daniel Gallego-Puyol [5], Jessica Golm [3,6], Igor García Irastorza [7], Chloe Malbrunot [3], Jordi Miralda-Escudé [4,8], Carlos Peña Garay [9,10], Javier Redondo [7,11] and Walter Wuensch [3]

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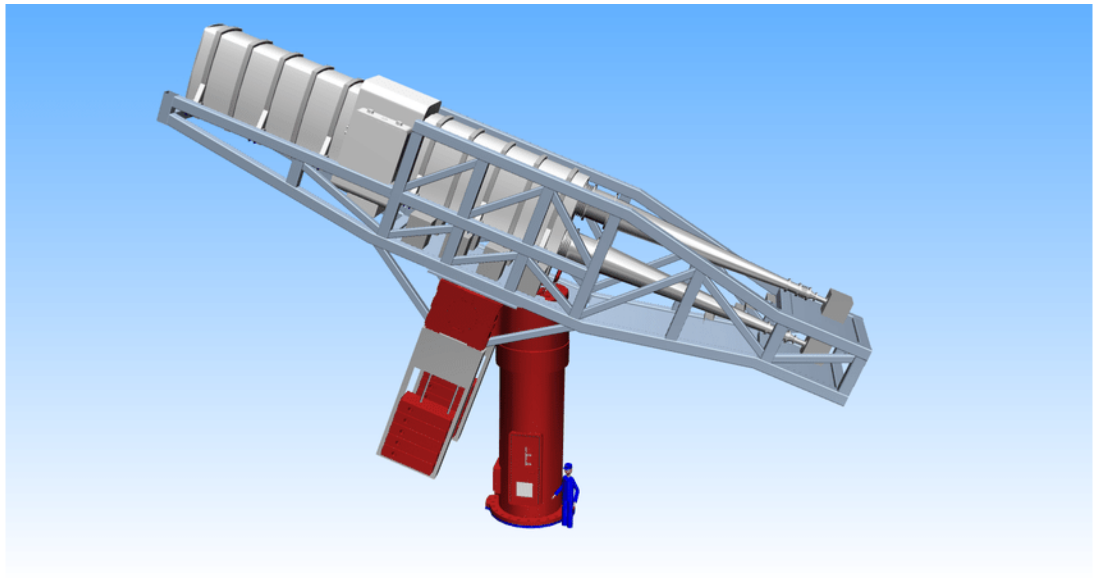

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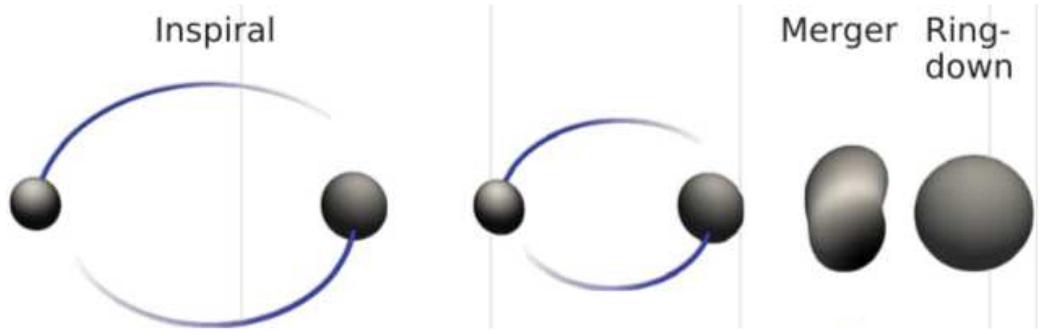
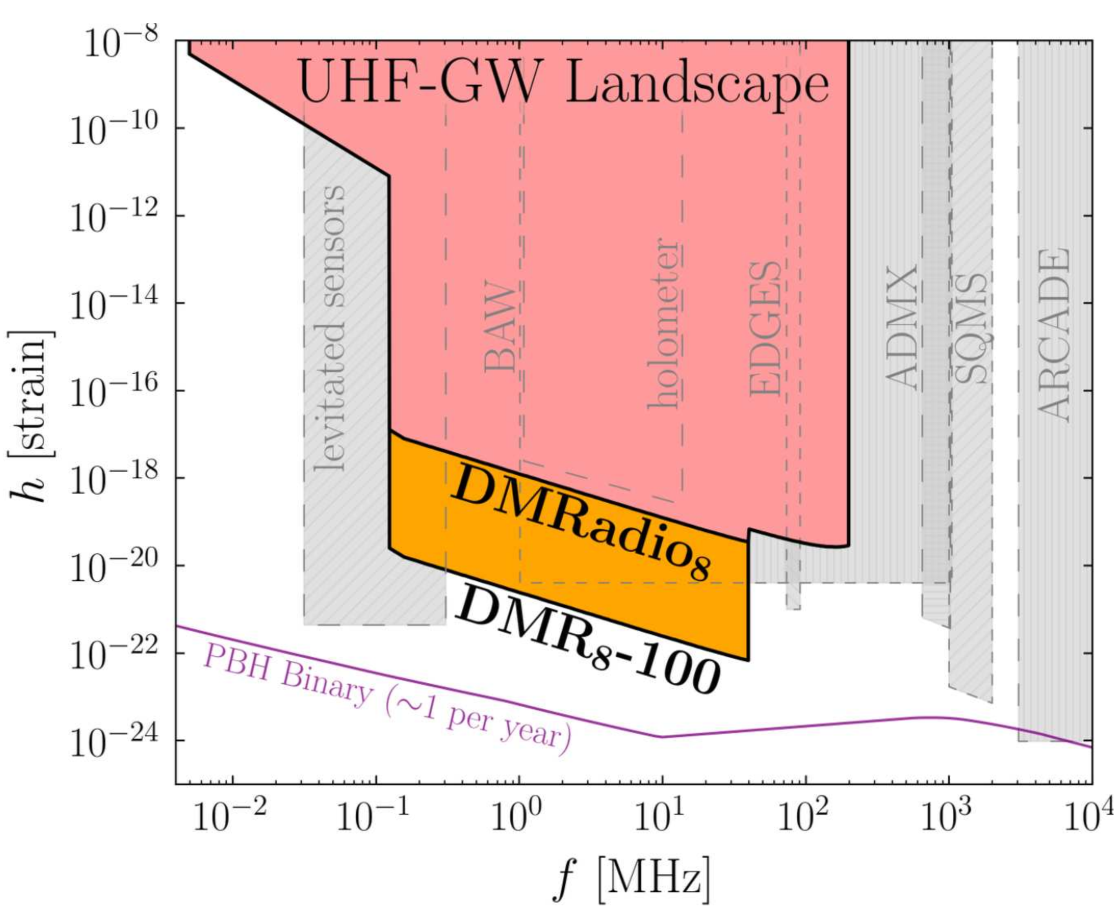
Gravitational waves?

Work in progress

Potential sources



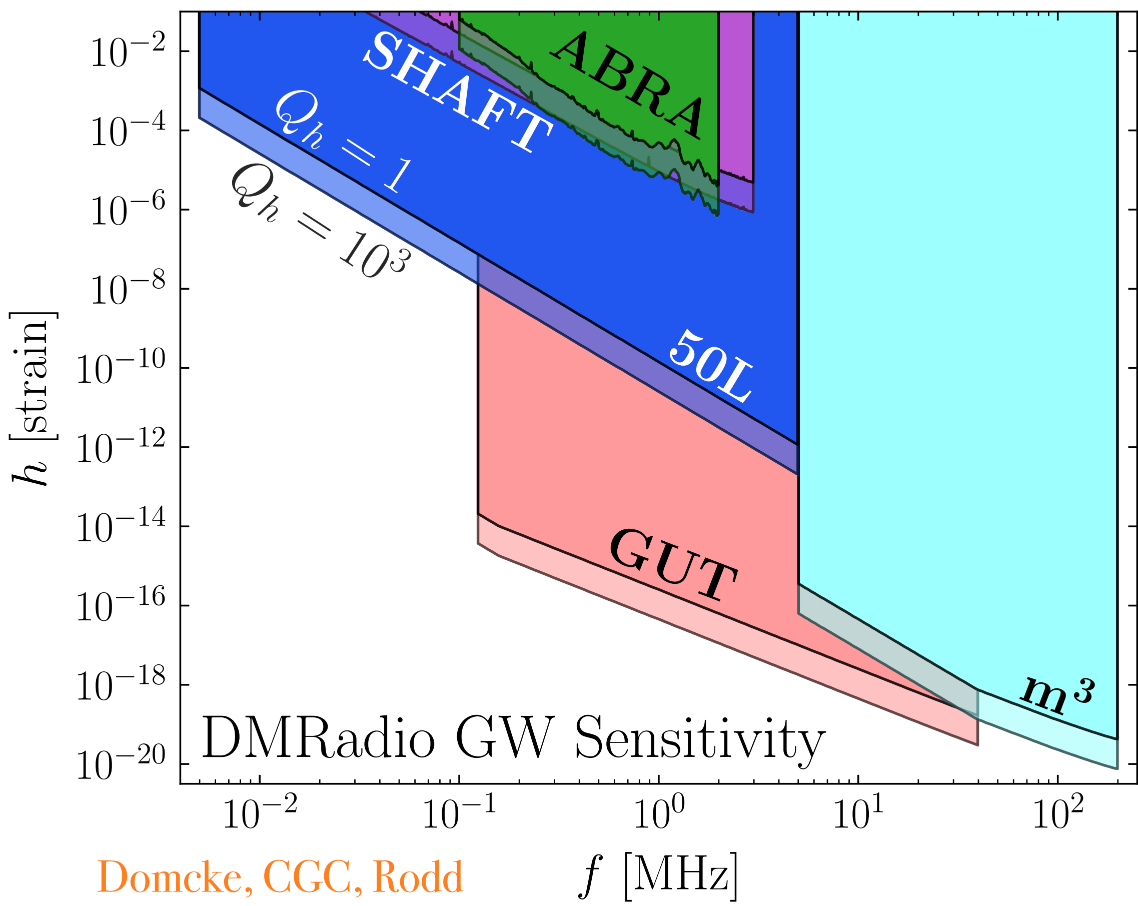
Domcke, CGC, Rodd



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

Conclusions

We provide a formulation of GW electrodynamics which demonstrates that low-mass axion haloscopes are also UHF-GW telescopes.



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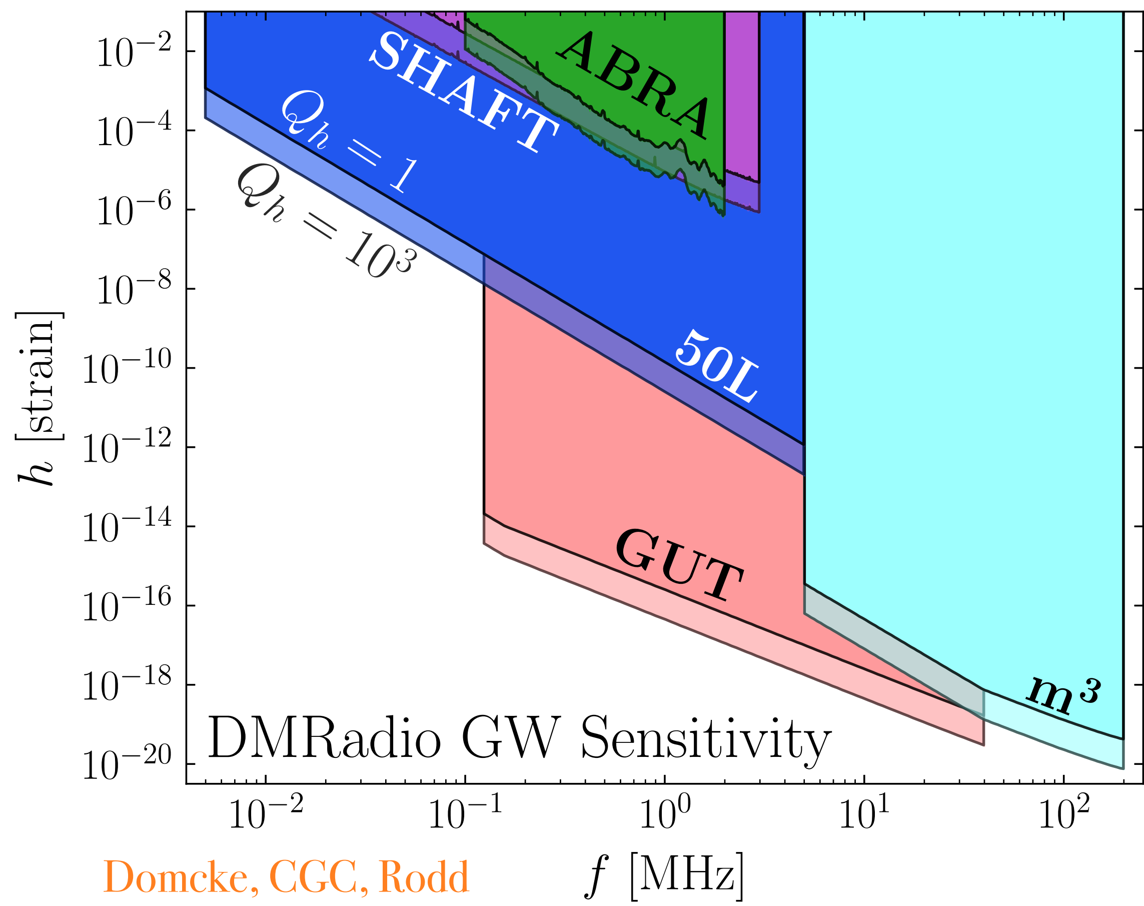

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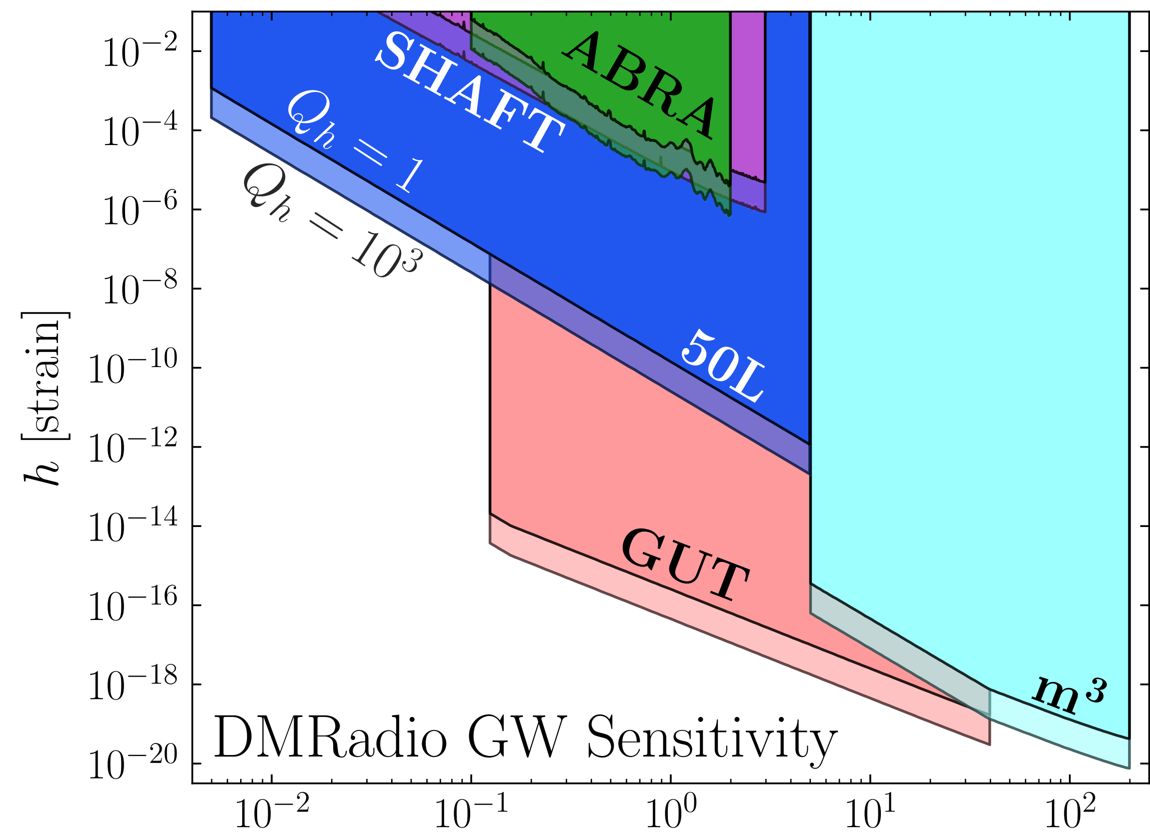

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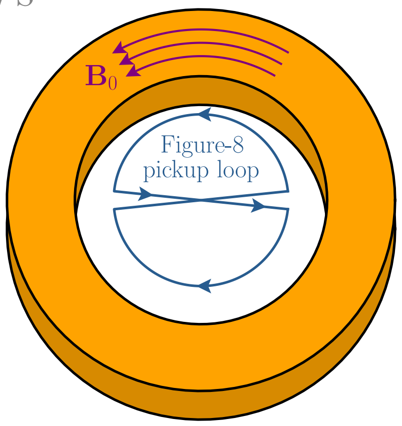

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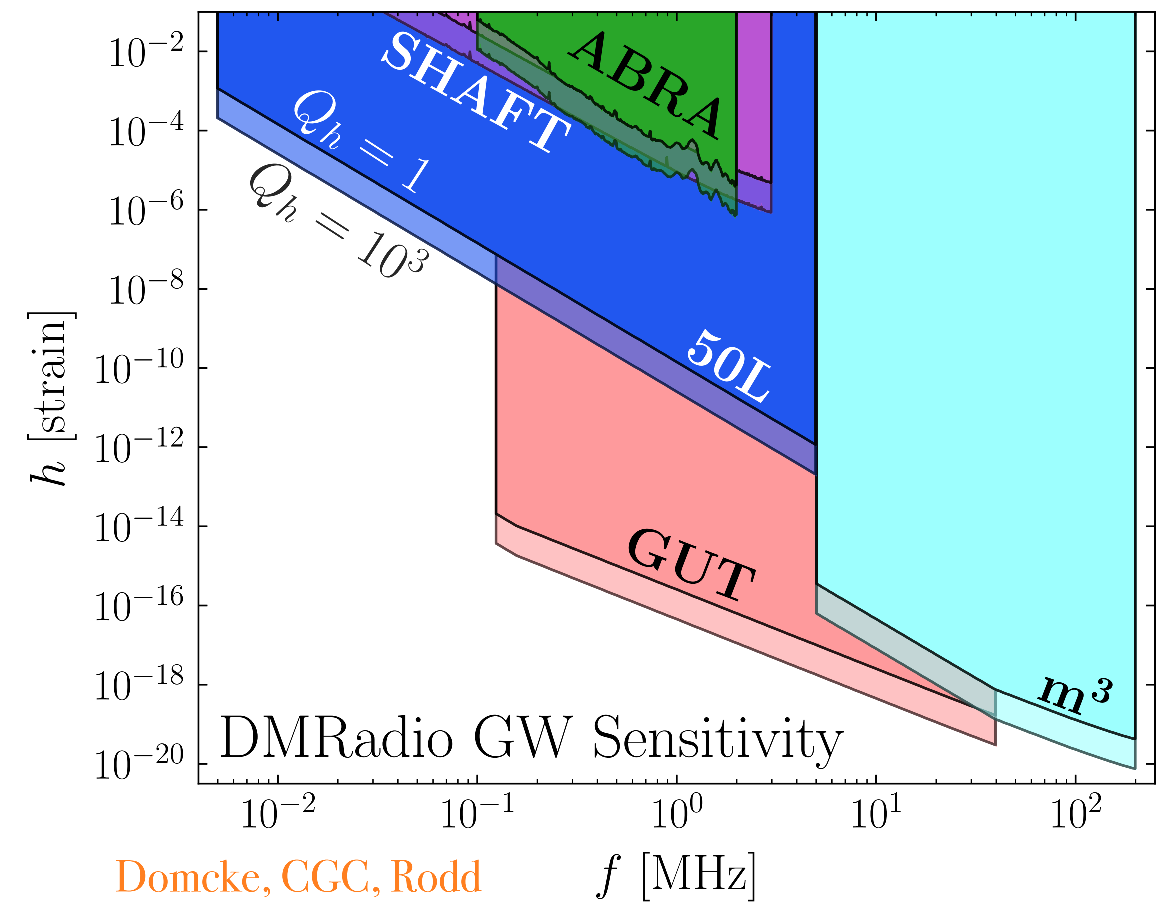

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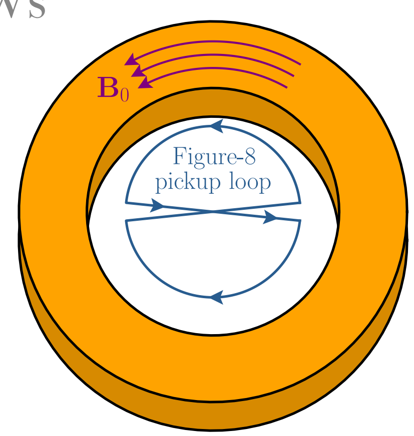

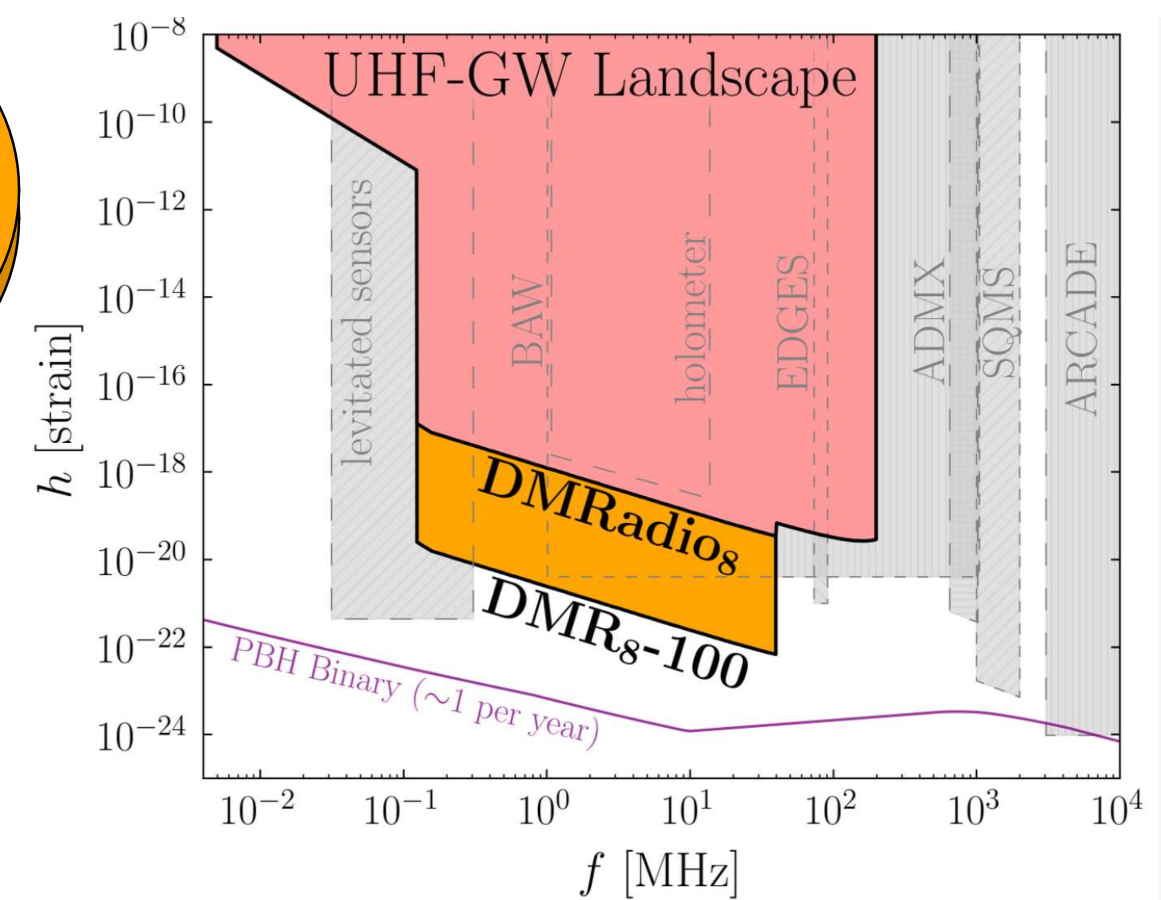

A number of distinct experimental proposals have coalesced on a strain sensitivity of 10^{-22} for MHz GWs, a level that is still orders of magnitude away from any signal of the early Universe. Whether we can hope to probe such strain sensitivities remains to be determined.