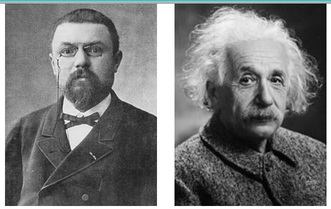
The CMB as a detector of high-frequency gravitational waves

Camilo A. Garcia Cely
Alexander von Humboldt fellow

CoCo meeting
Cosmología en Colombia

In collaboration with Valerie Domcke,
based on arXiv:2006.01161 [astro-ph.CO]

Gravitational Waves



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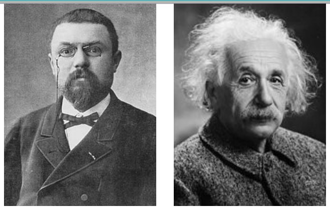

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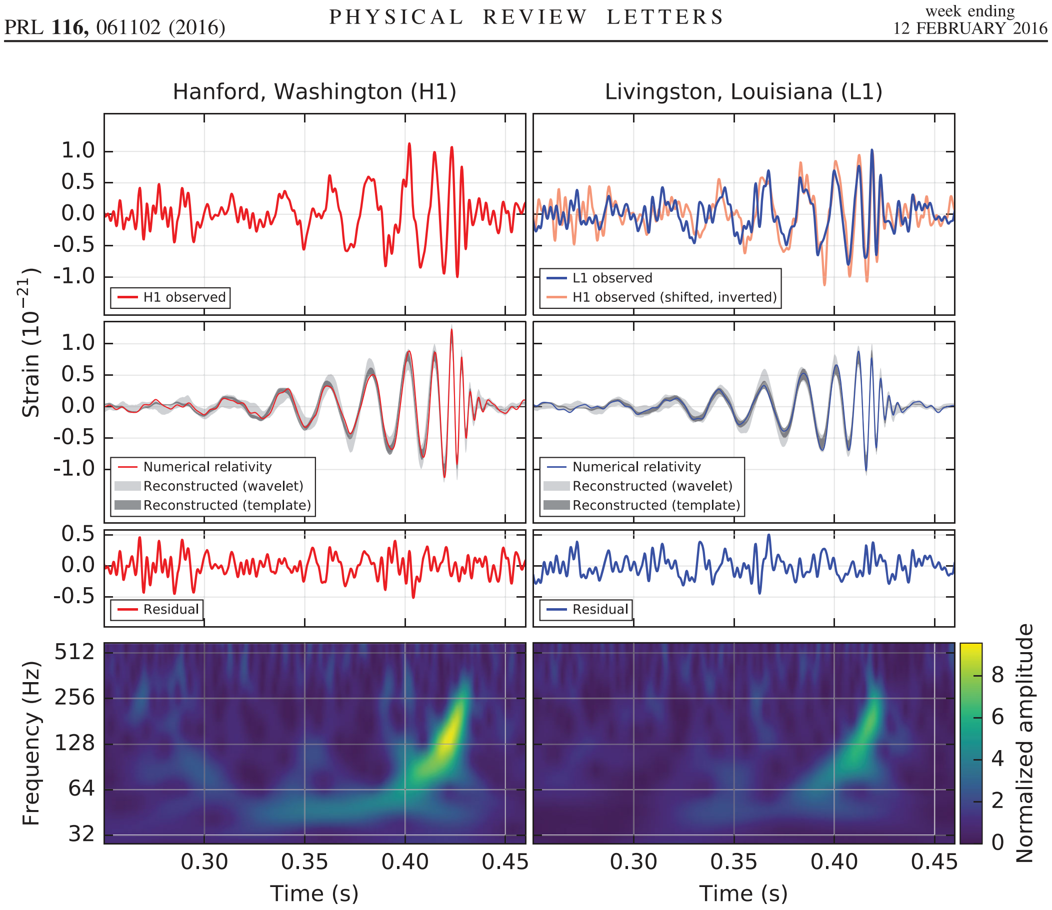
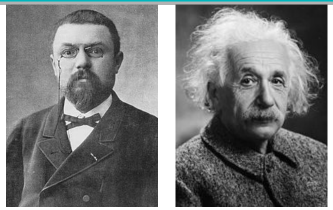


PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Terrestrial interferometers

Gravitational Waves



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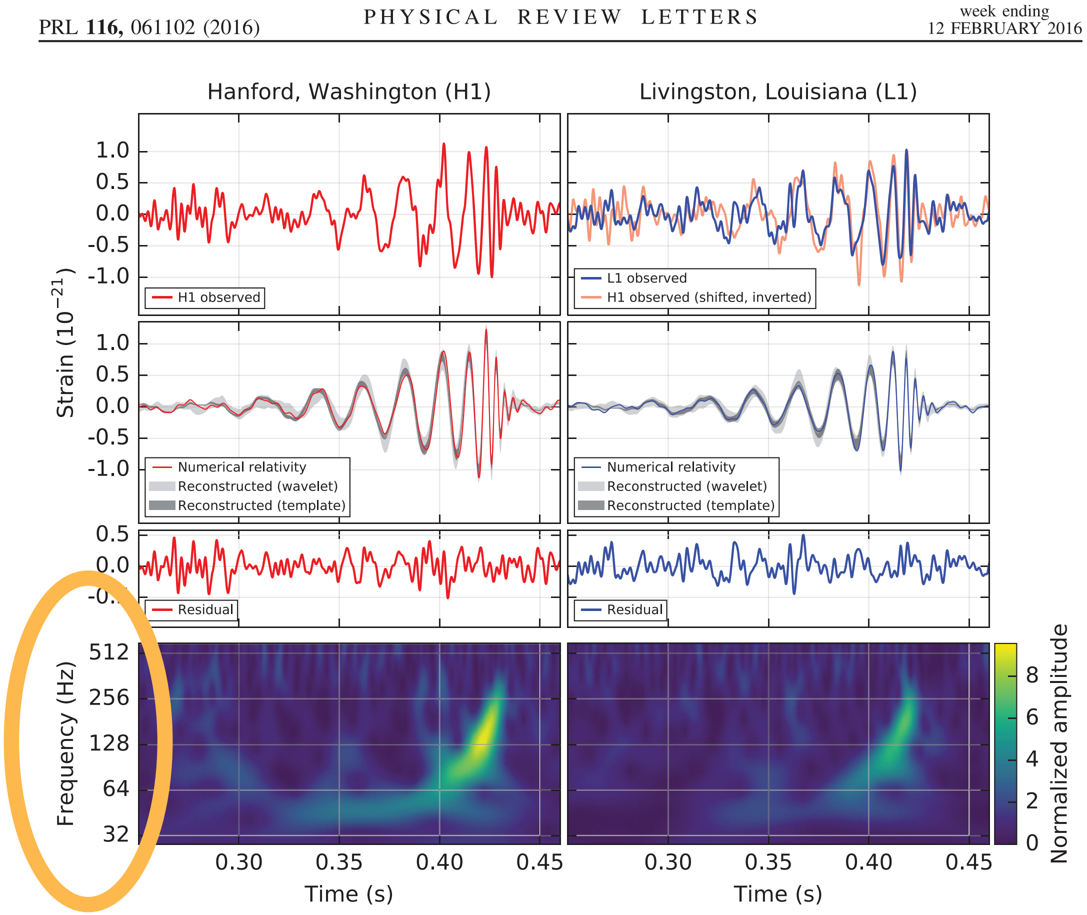

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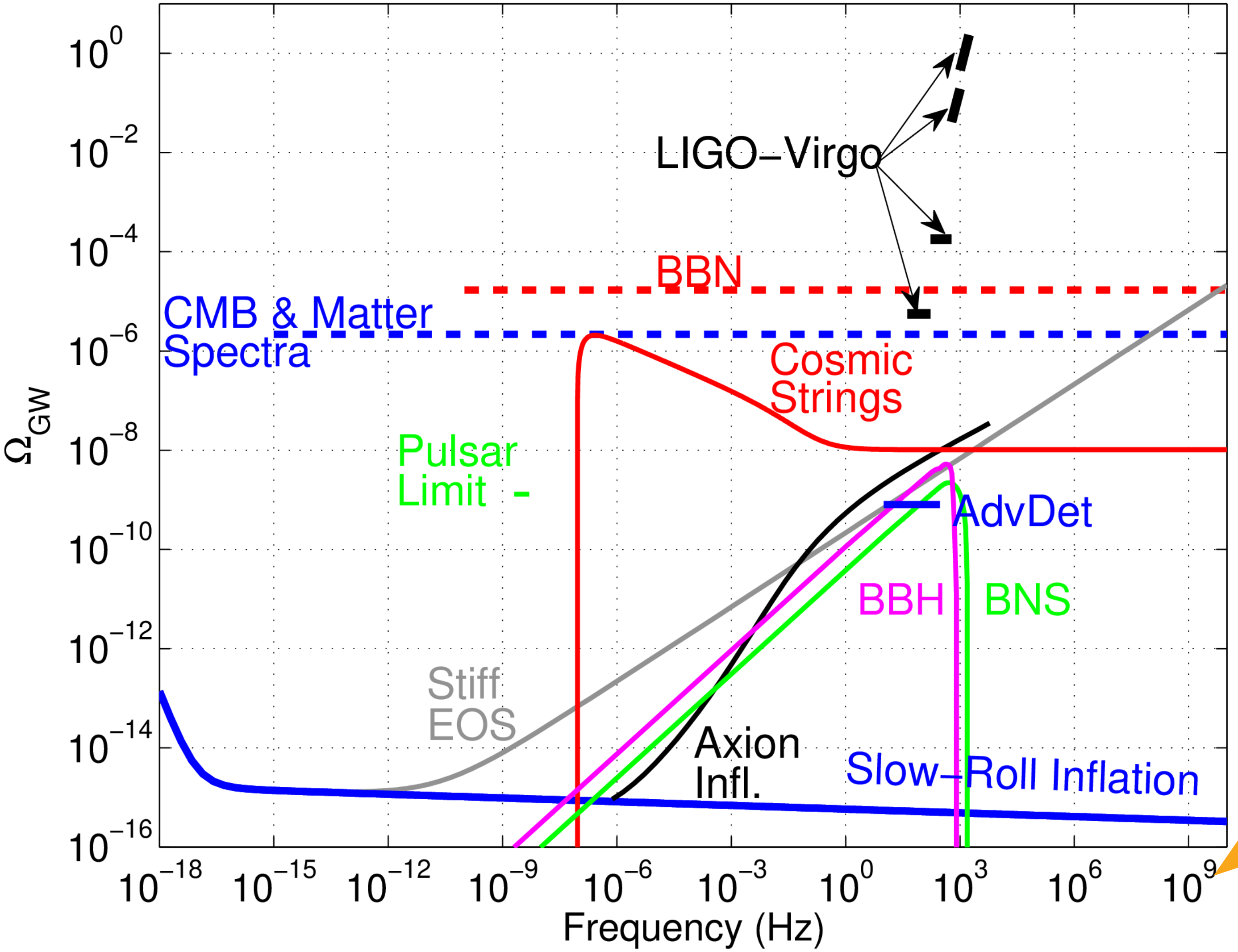
Gravitational waves spectrum

LIGO-VIRGO coll.'14



our work
Domcke,CGC 2020

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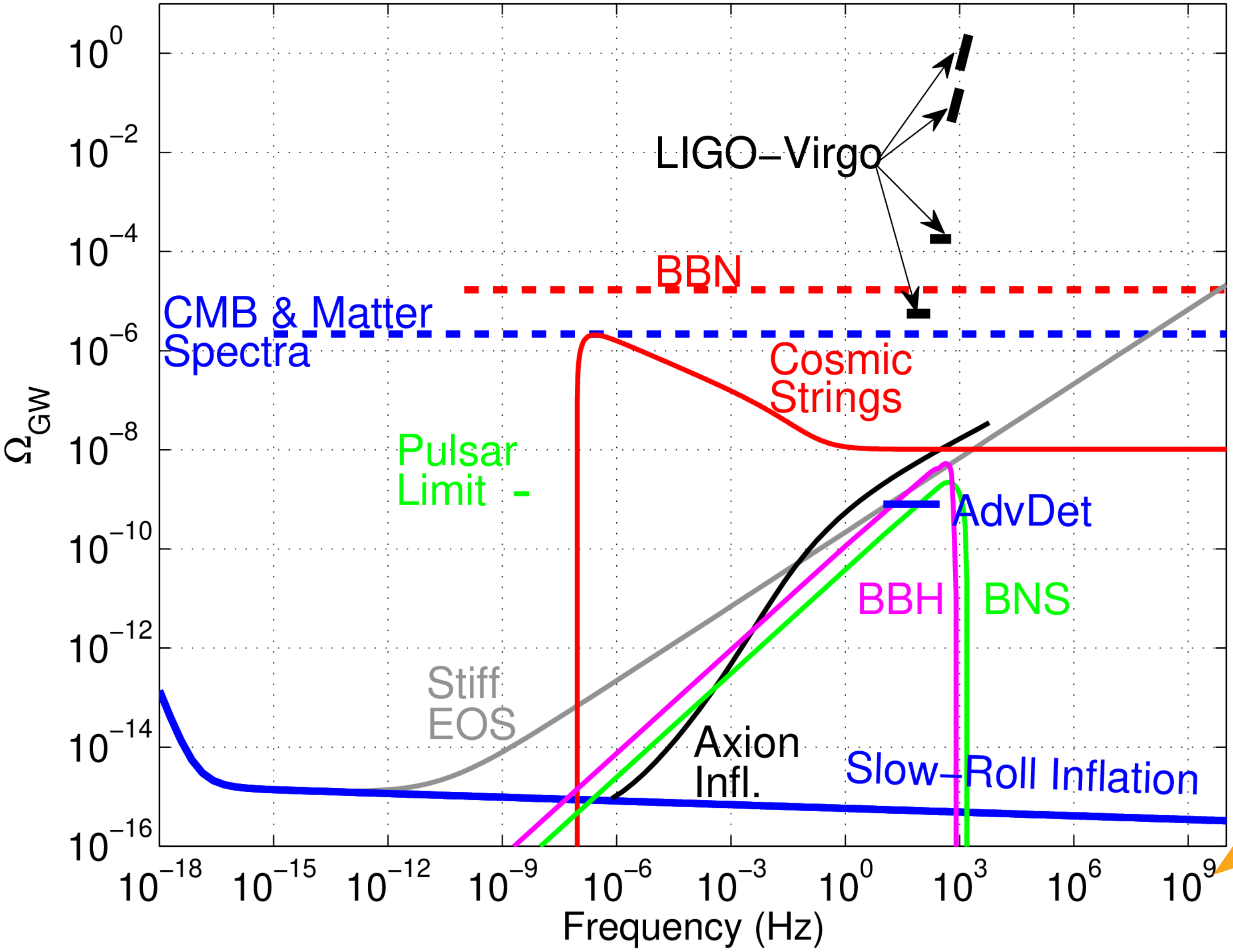
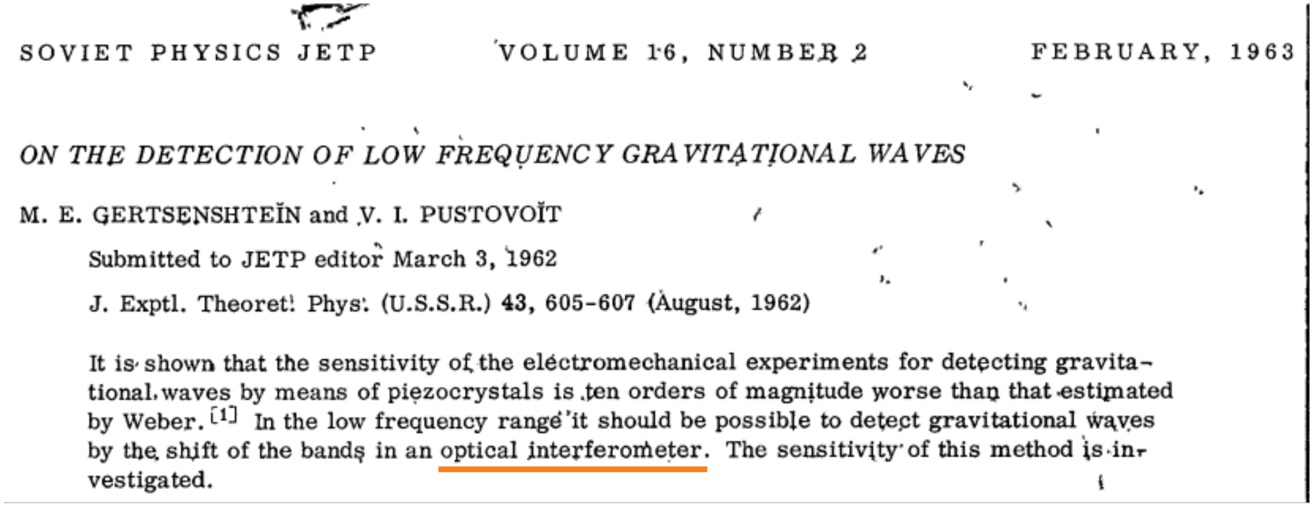


Cosmological constraints on radiation (Neff)

our work
Domcke,CGC 2020

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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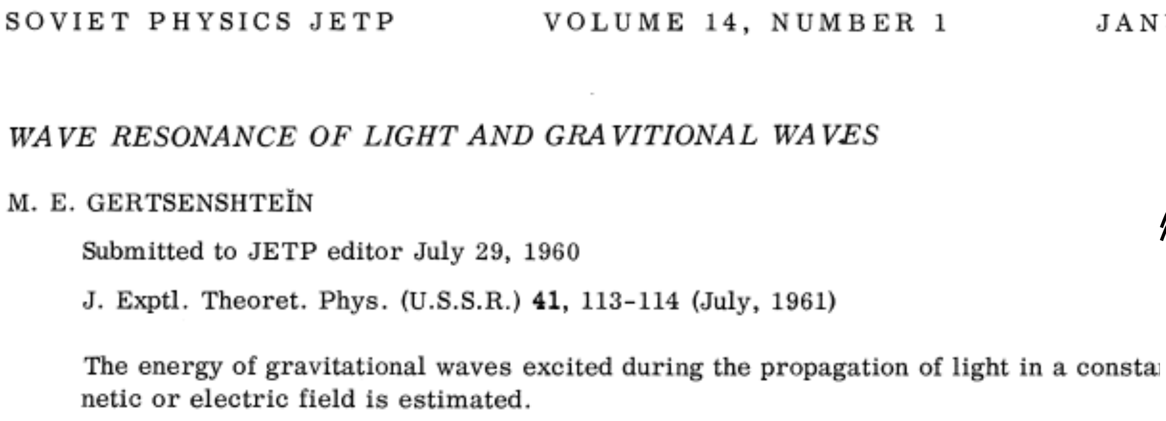

SOVIET PHYSICS JETP VOLUME 14, NUMBER 1 JANUARY, 1962

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 consta
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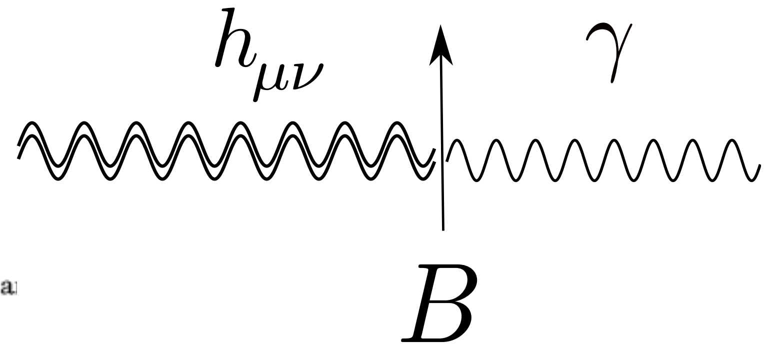

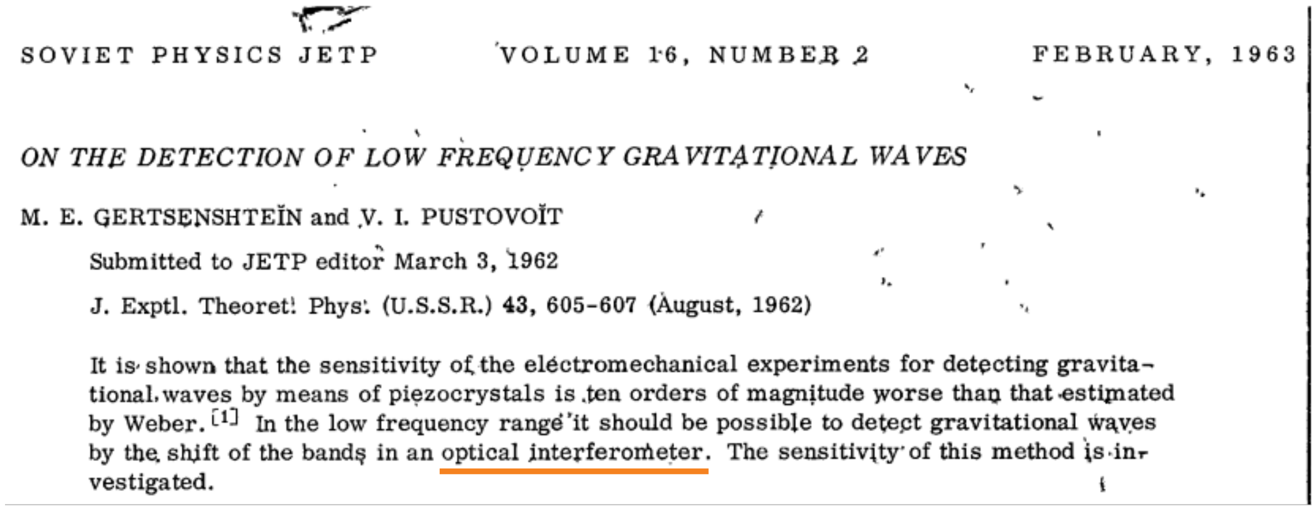

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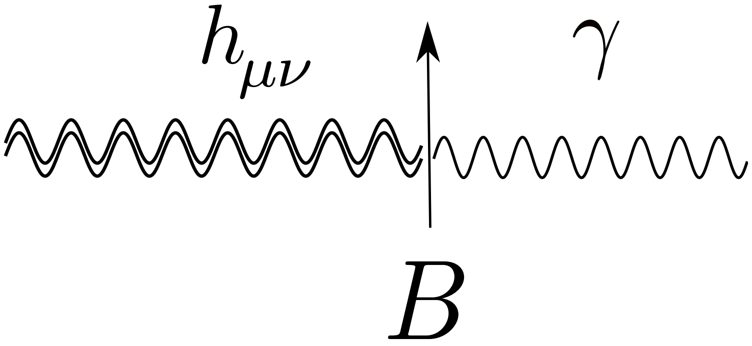

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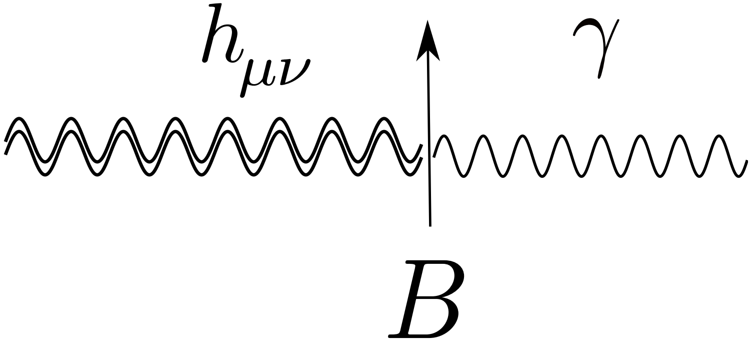
Raffelt, Stodolsk ‘89



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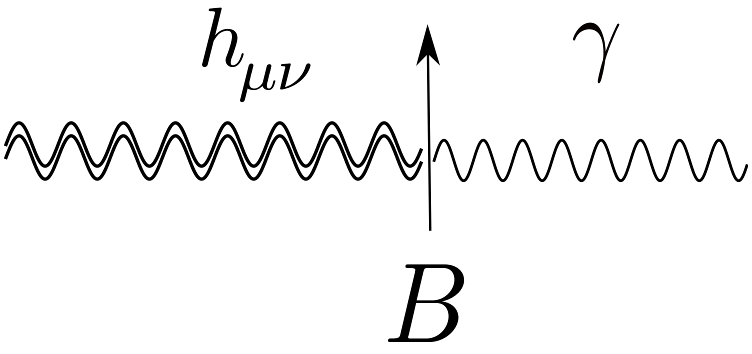
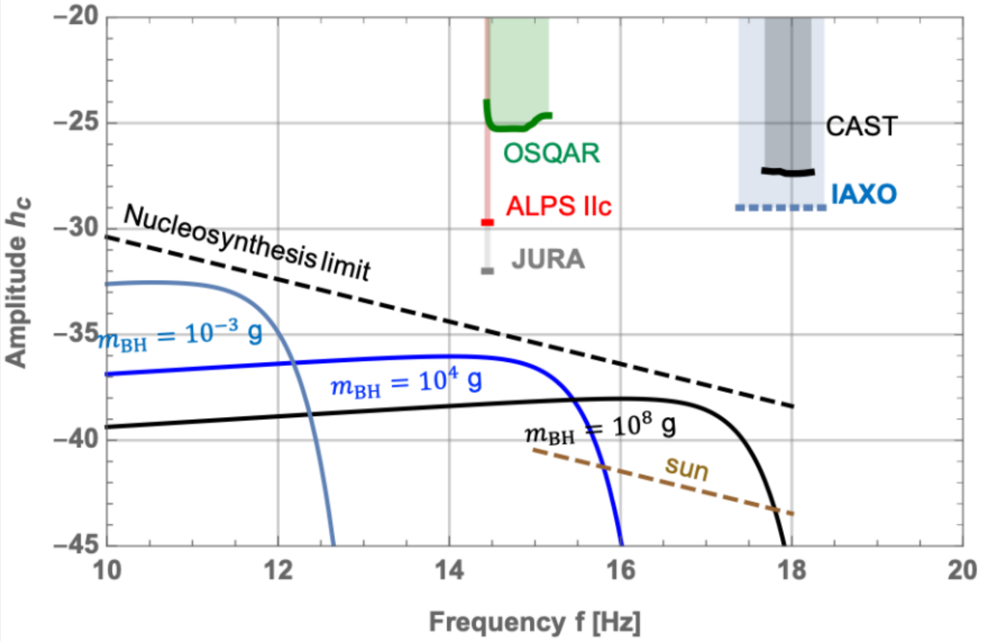


Ejlli et al 2020



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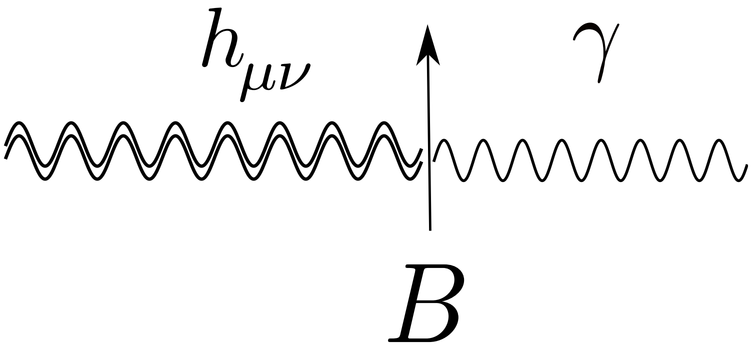

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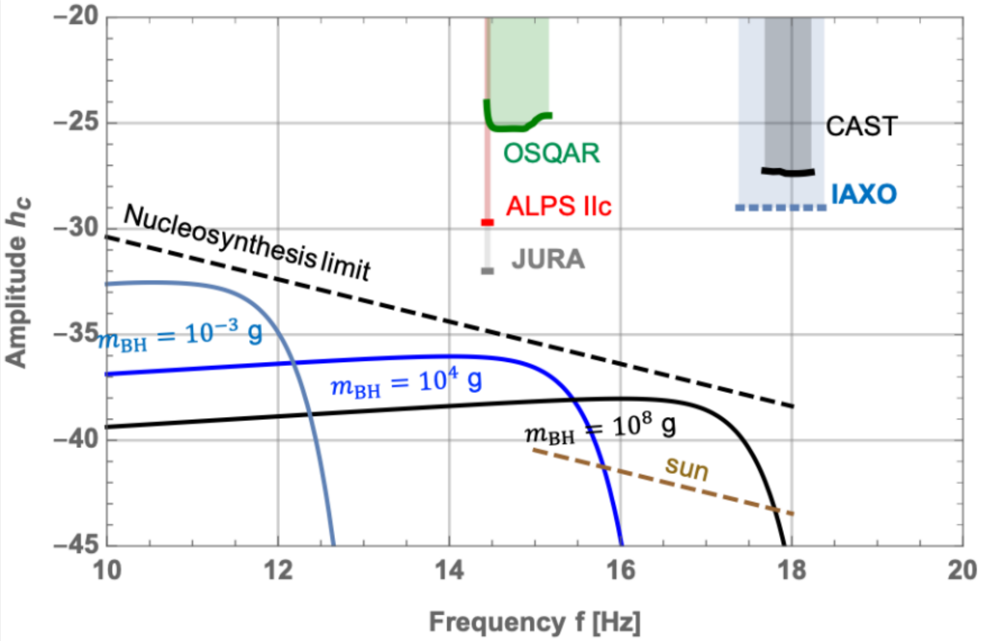

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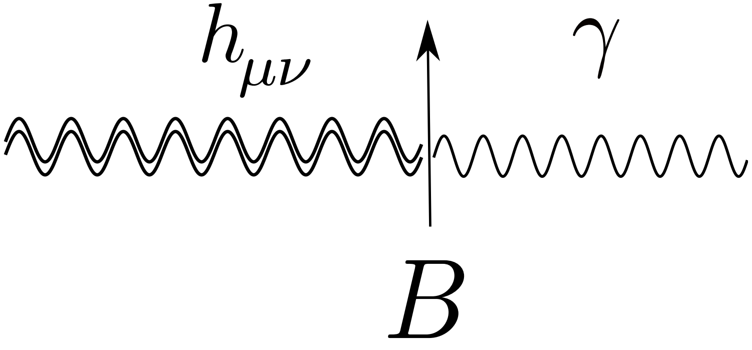

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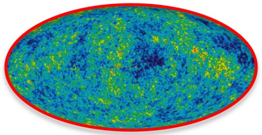
Distortions of the CMB?

Domcke,CGC 2020



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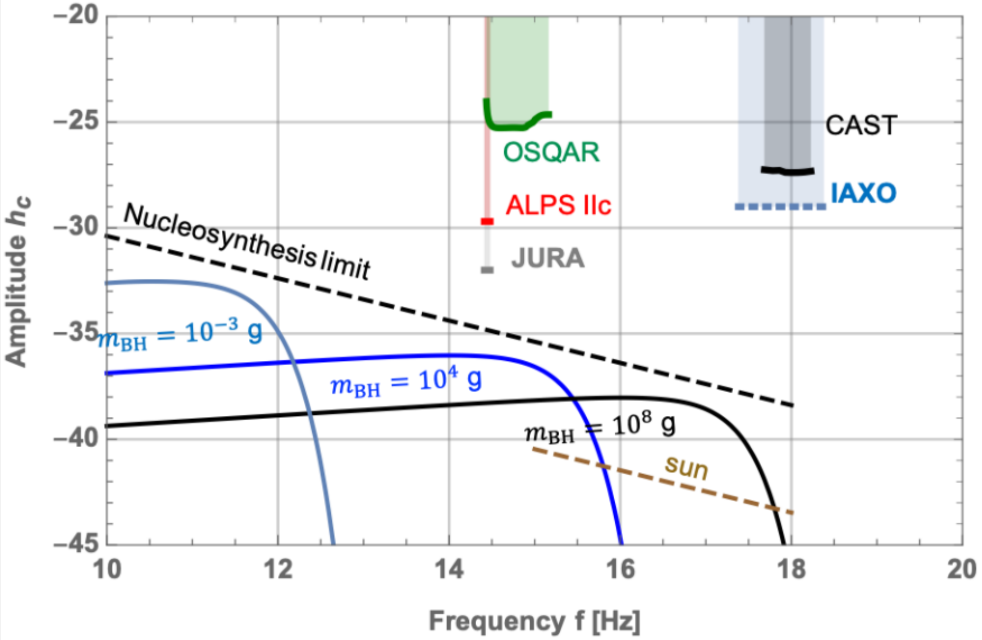

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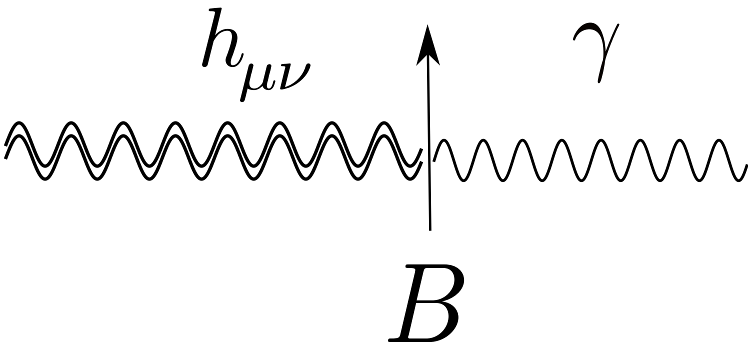

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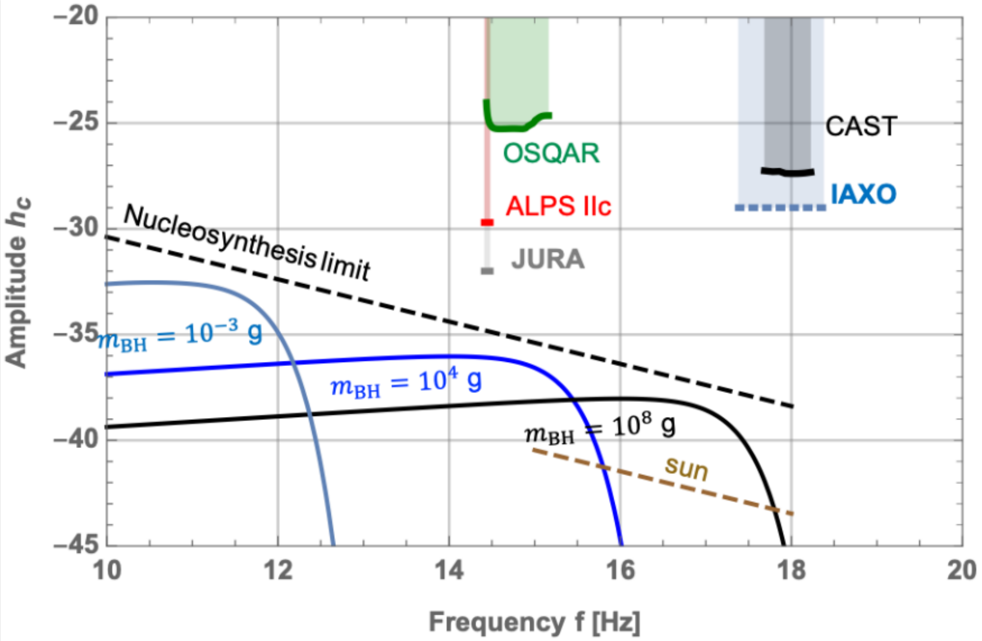

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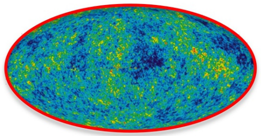
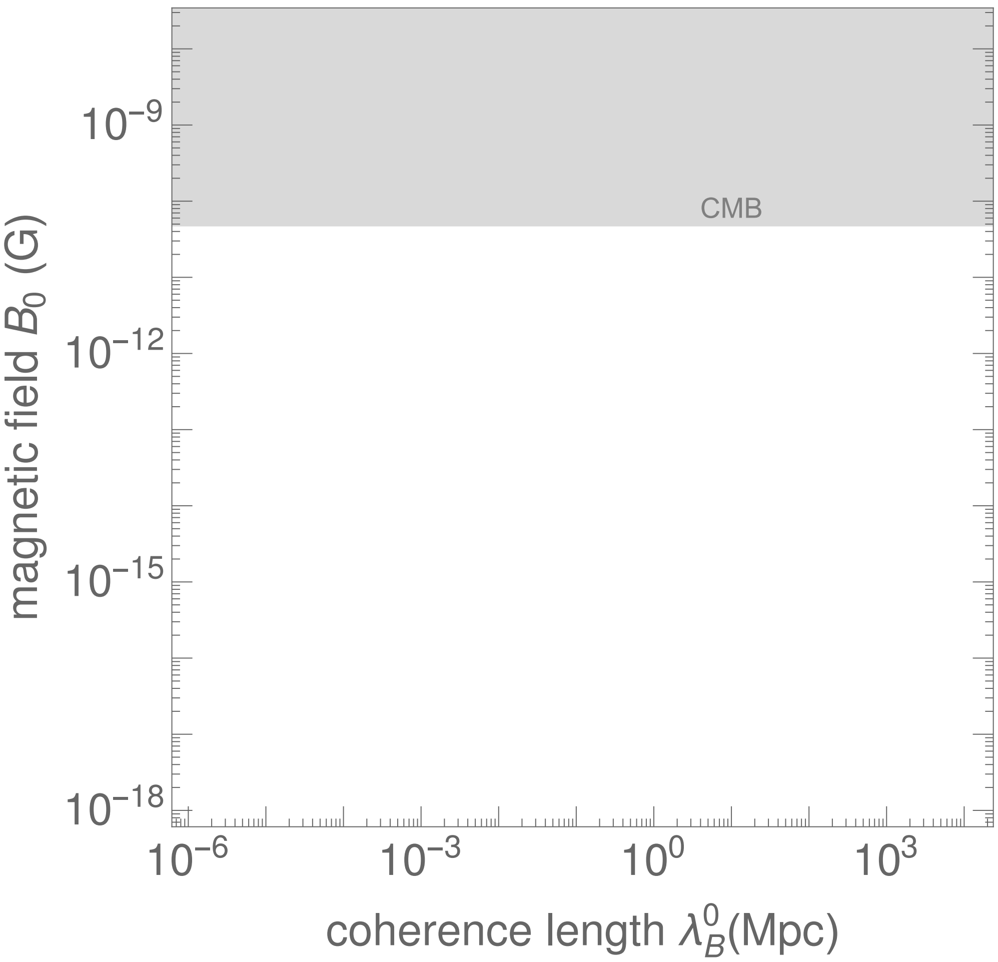
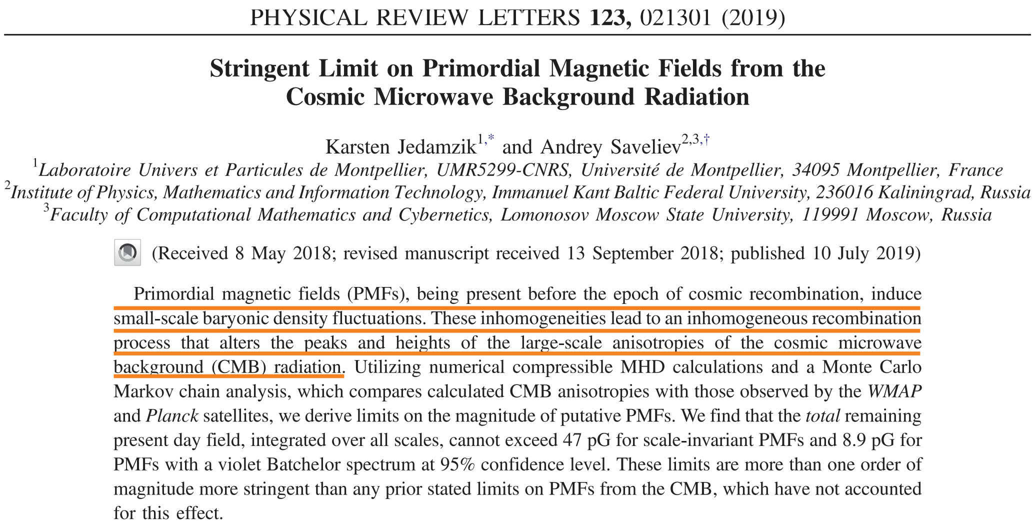


Domcke, CGC 2020
Dolgov, Ejlli 2012
Pshirkov, Baskaran 2009
Chen 1995
…….

Cosmic Magnetic Fields in 2020

Domcke,CGC 2020





PHYSICAL REVIEW LETTERS **123,** 021301 (2019)

Stringent Limit on Primordial Magnetic Fields from the Cosmic Microwave Background Radiation

Karsten Jedamzik[1,*] and Andrey Saveliev[2,3,†]

[1]*Laboratoire Univers et Particules de Montpellier, UMR5299-CNRS, Université de Montpellier, 34095 Montpellier, France*
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(Received 8 May 2018; revised manuscript received 13 September 2018; published 10 July 2019)

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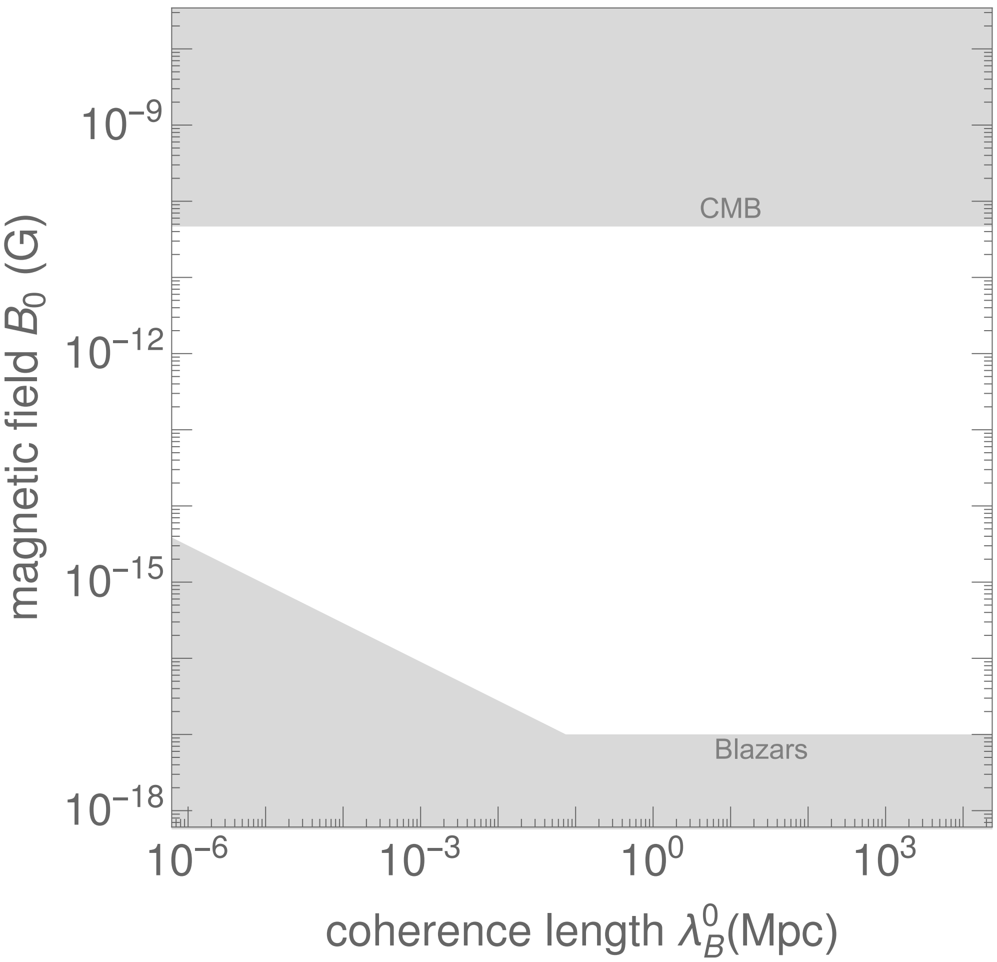

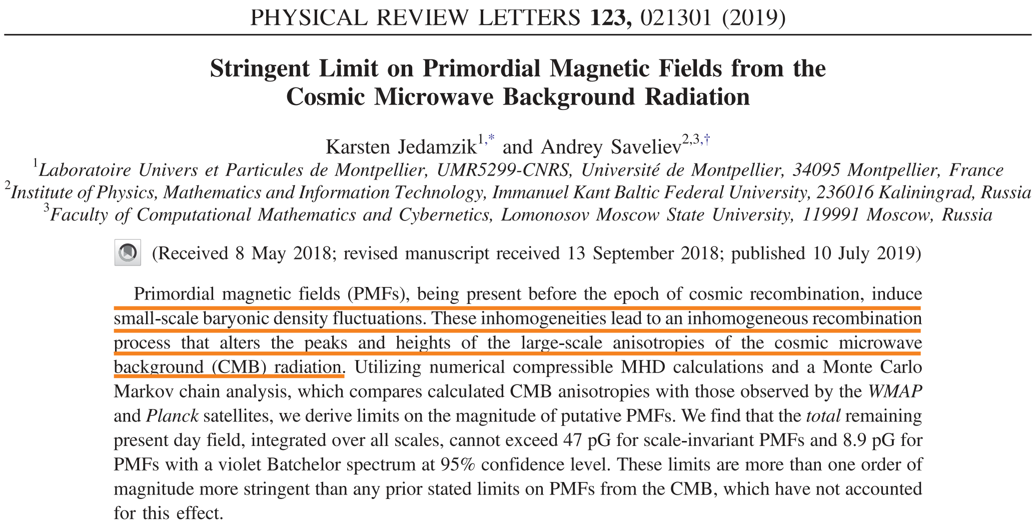

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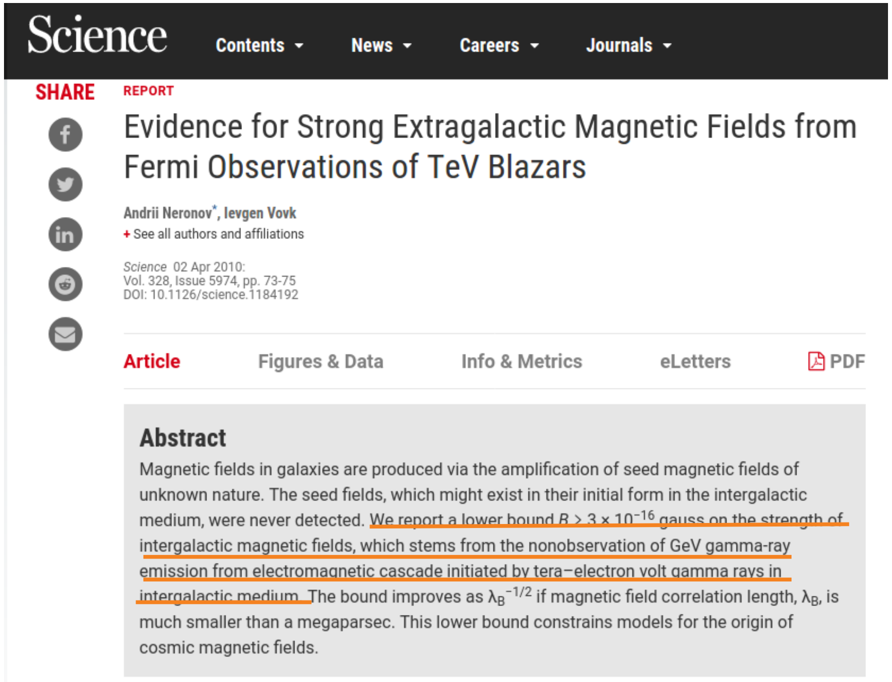

REPORT

Evidence for Strong Extragalactic Magnetic Fields from Fermi Observations of TeV Blazars

Andrii Neronov*, Ievgen Vovk
+ See all authors and affiliations

Science 02 Apr 2010:
Vol. 328, Issue 5974, pp. 73-75
DOI: 10.1126/science.1184192

Abstract

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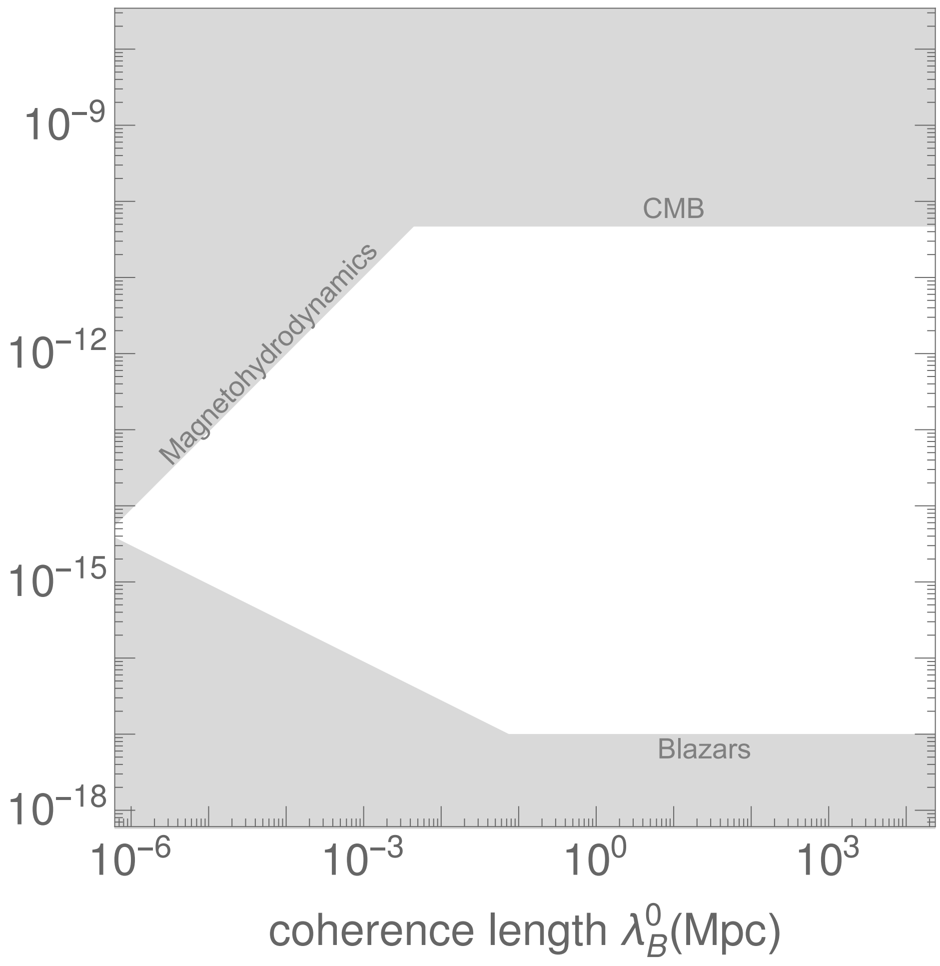
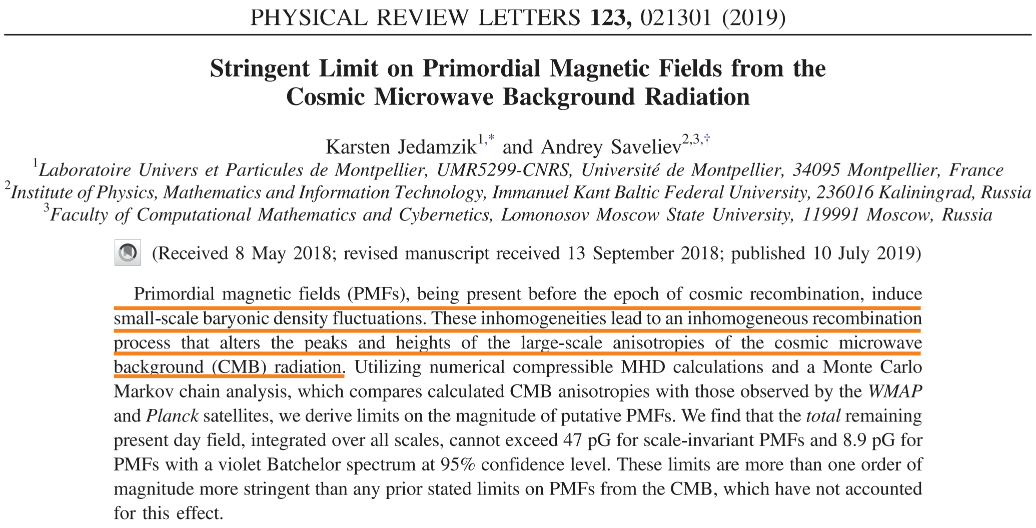
Domcke,CGC 2020





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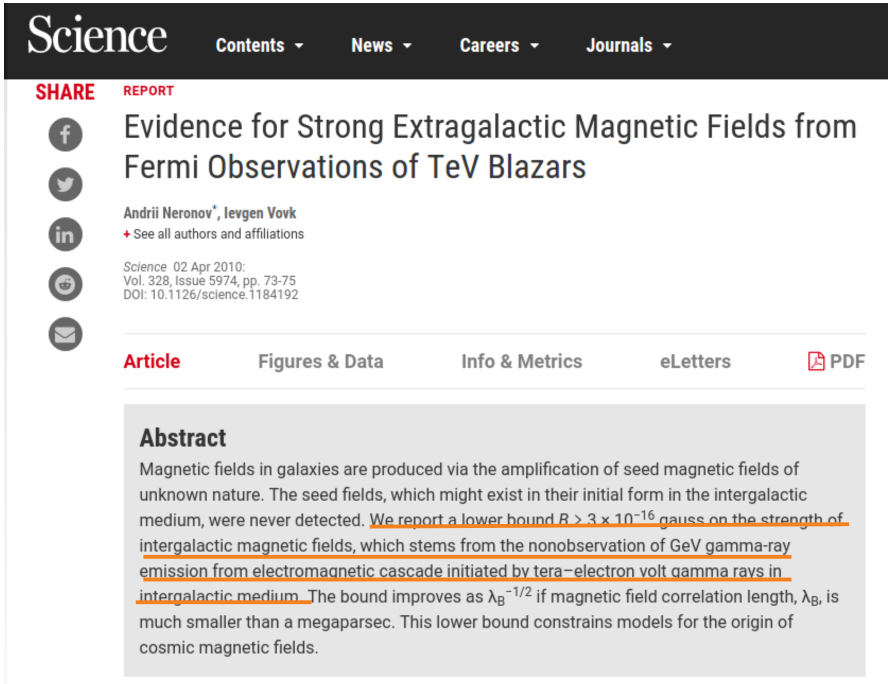

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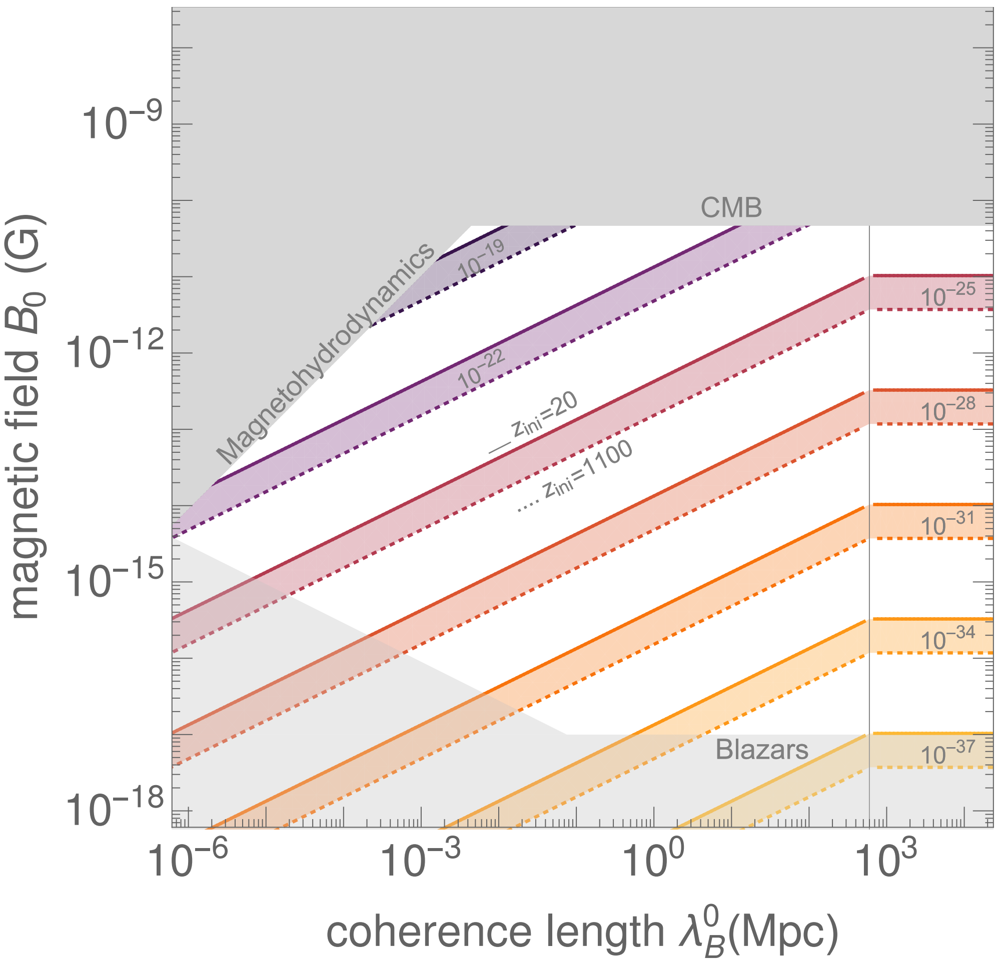
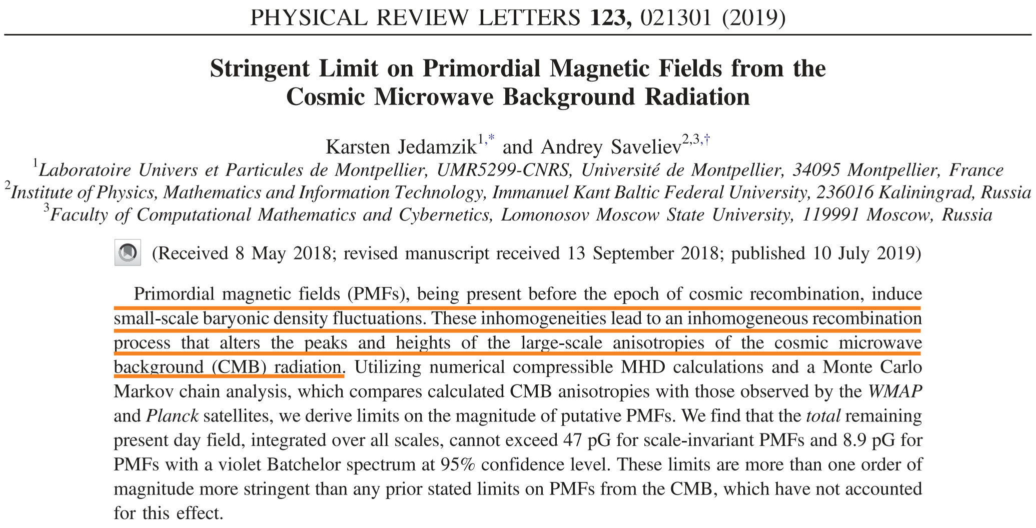
Domcke,CGC 2020



$$\mathcal{P} \equiv \int_{l.o.s.} \langle \Gamma_{g\leftrightarrow\gamma} \rangle dt$$



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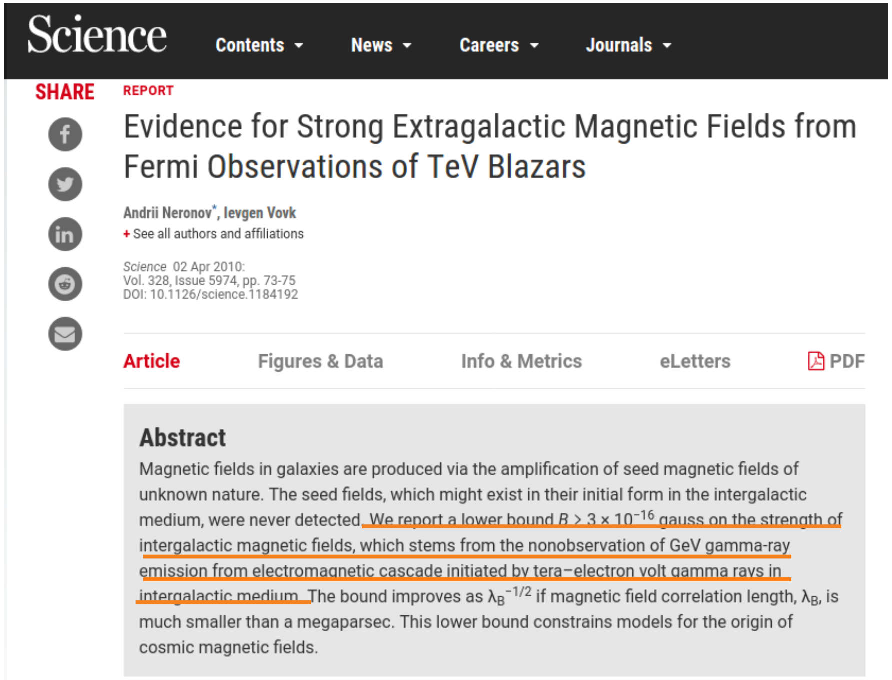

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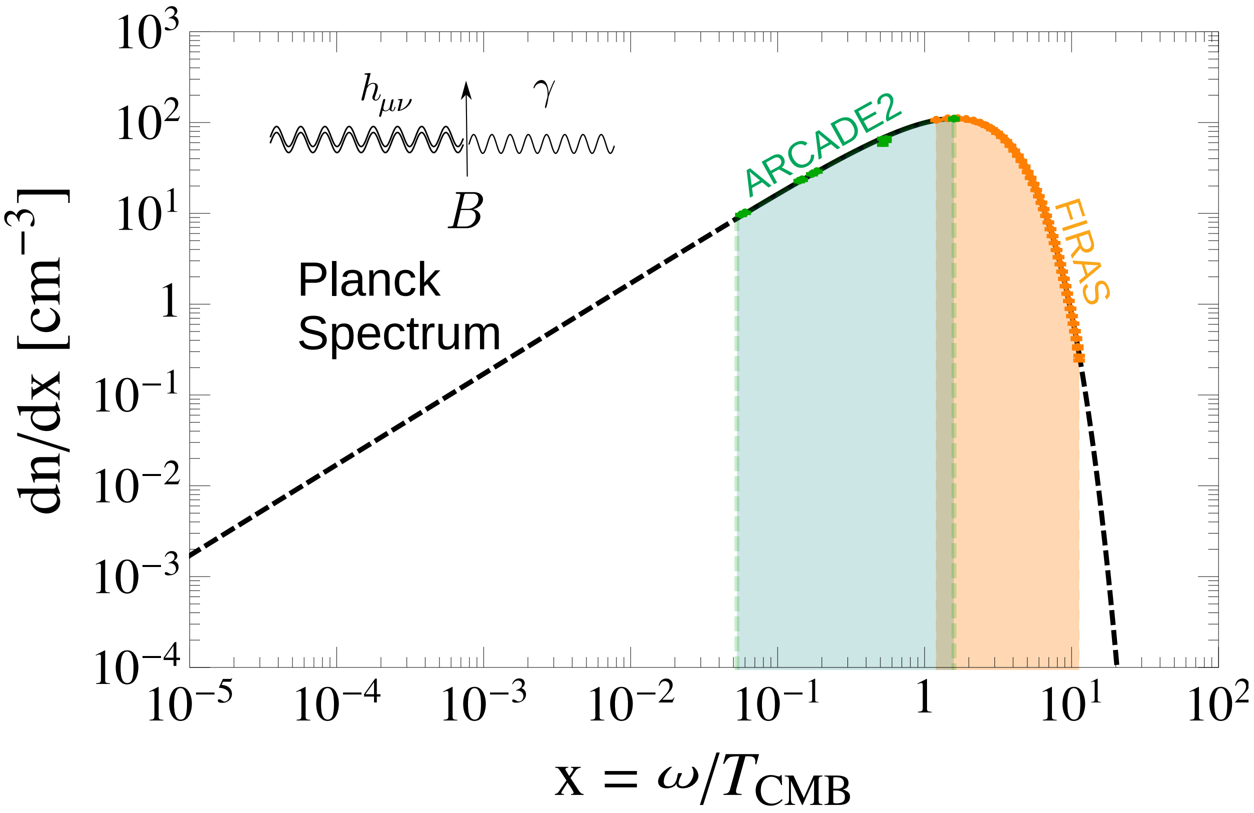

Absolute **R**adiometer for **C**osmology, **A**strophysics, and **D**iffuse **E**mission

THE ASTROPHYSICAL JOURNAL

ARCADE 2 MEASUREMENT OF THE ABSOLUTE SKY BRIGHTNESS AT 3-90 GHz

D. J. Fixsen[1], A. Kogut[2], S. Levin[3], M. Limon[4], P. Lubin[5], P. Mirel[6], M. Seiffert[3], J. Singal[7], E. Wollack[2], T. Villela[8] +Show full author list

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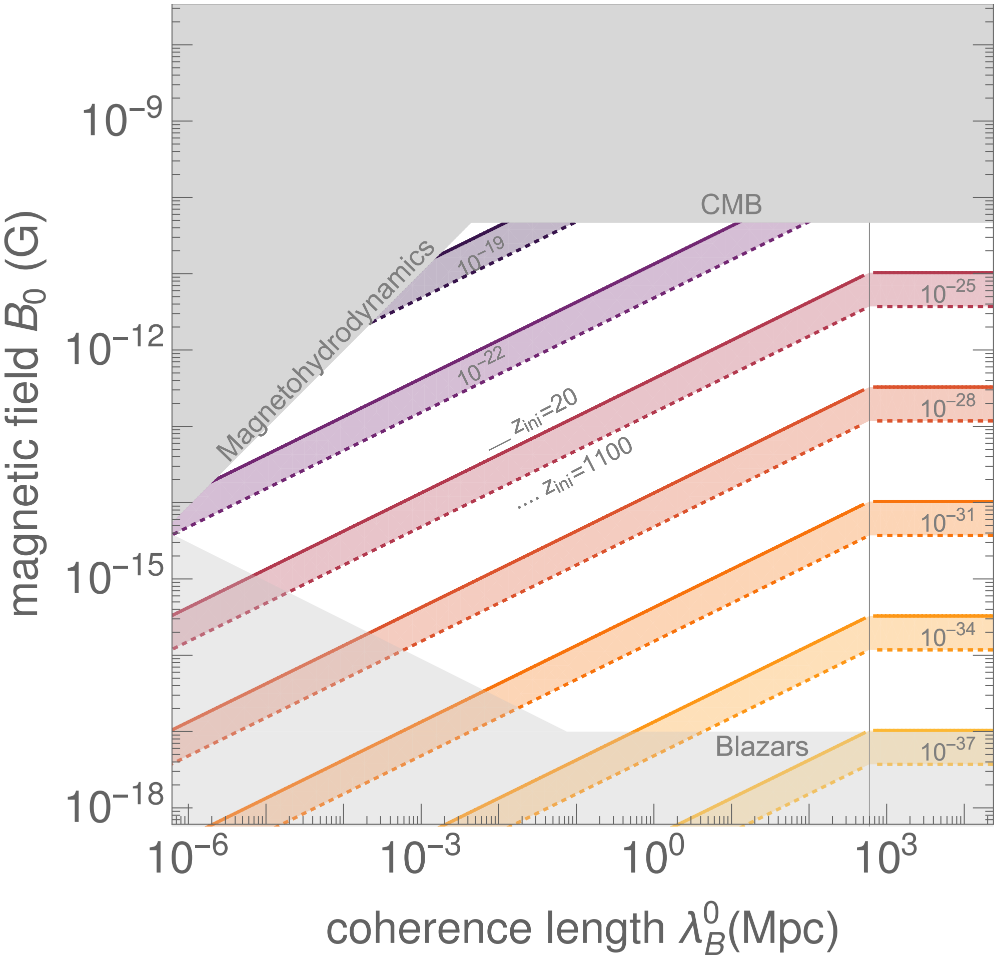
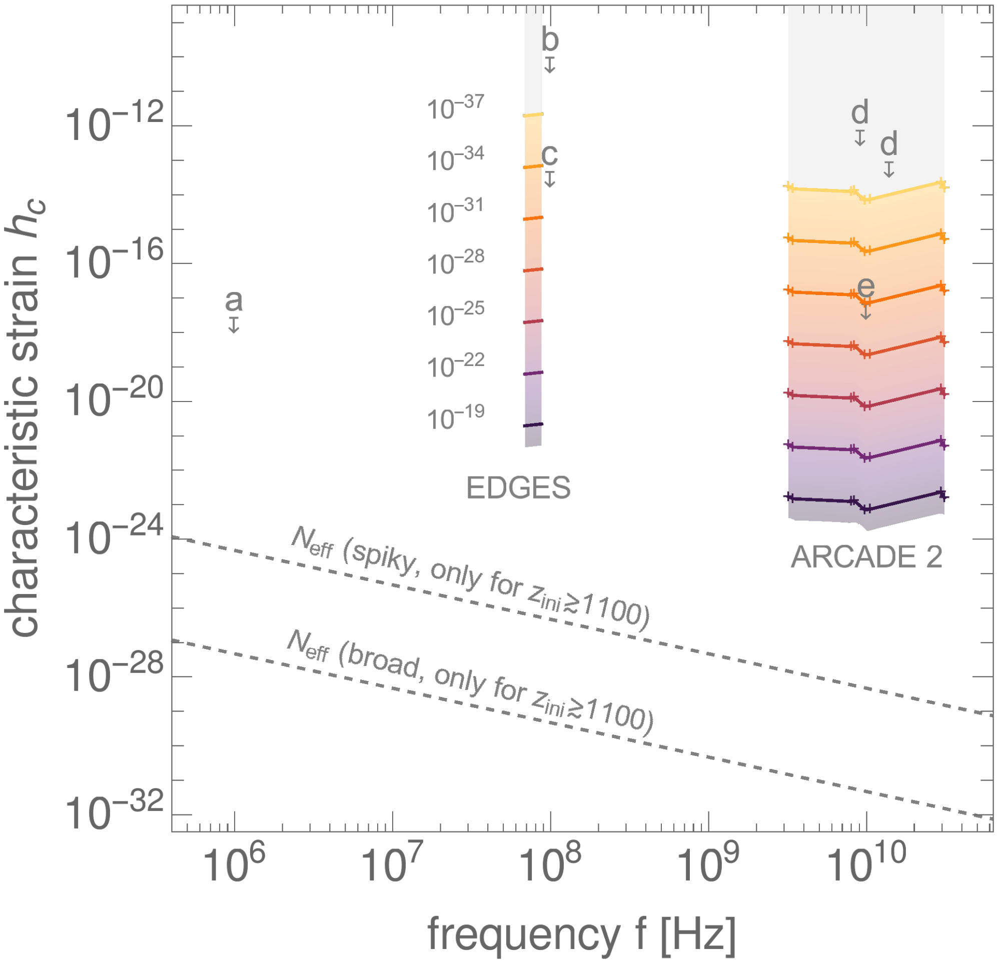
The Astrophysical Journal, Volume 734, Number 1

Upper bounds on stochastic gravitational waves

Domcke,CGC 2020





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

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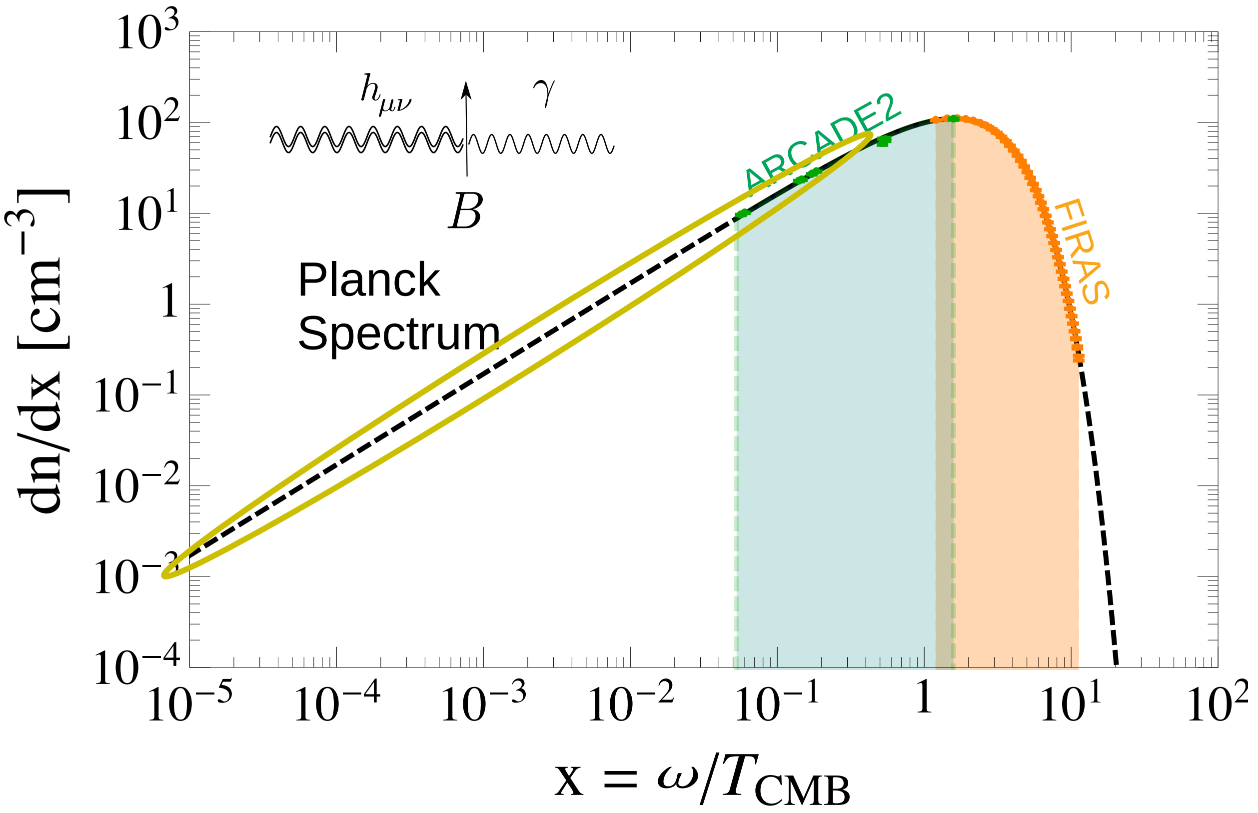

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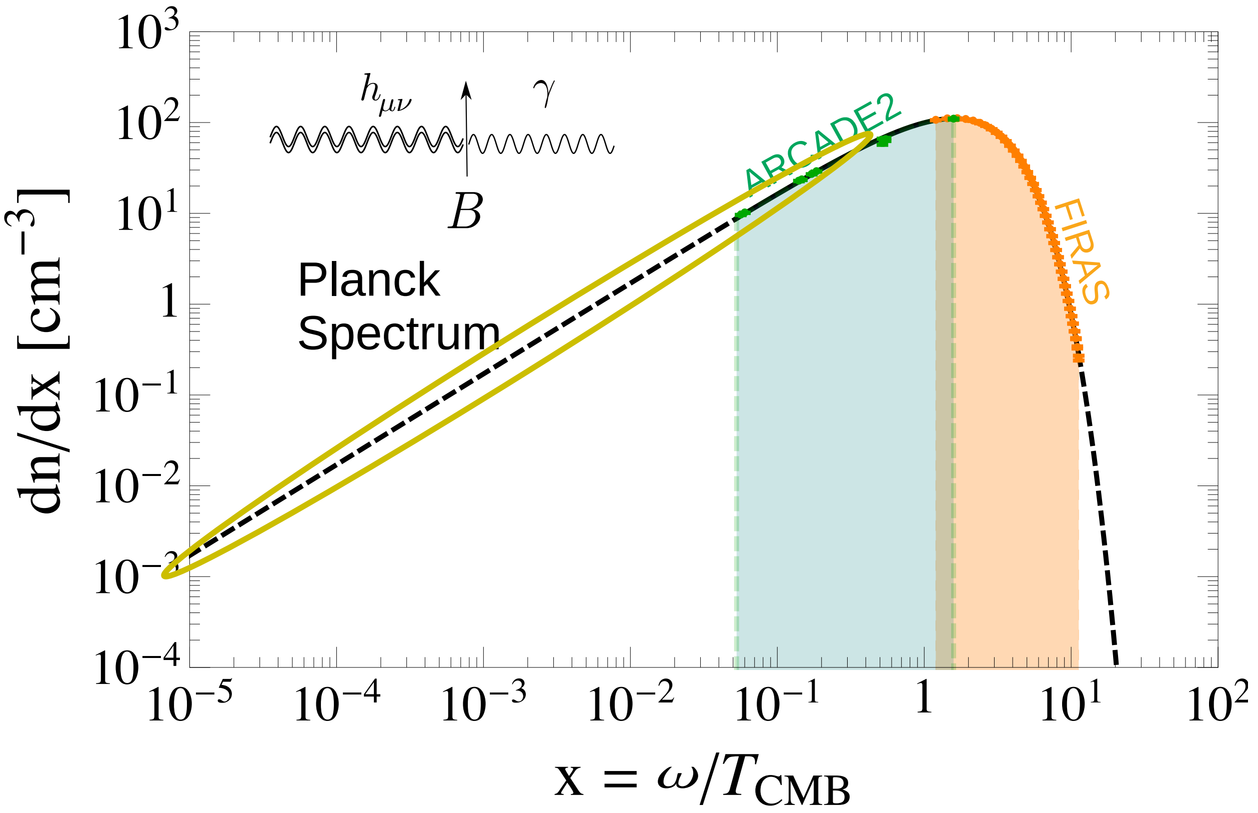
The Astrophysical Journal, Volume 734, Number 1

Rayleigh-Jeans tail

- Largely unexplored, with upcoming advances in radio astronomy probing it in the near future.

CMB distortions in 2020



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Absolute **R**adiometer for **C**osmology, **A**strophysics, and **D**iffuse **E**mission

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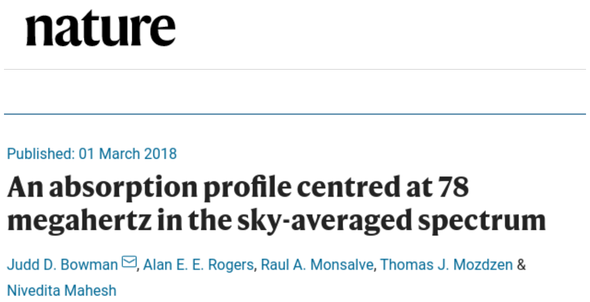


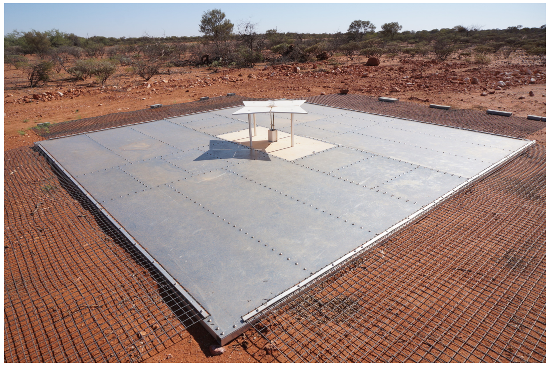
nature

Published: 01 March 2018

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

Judd D. Bowman, Alan E. E. Rogers, Raul A. Monsalve, Thomas J. Mozdzen & Nivedita Mahesh

Experiment to **D**etect the **G**lobal **E**poch of Reionization **S**ignature



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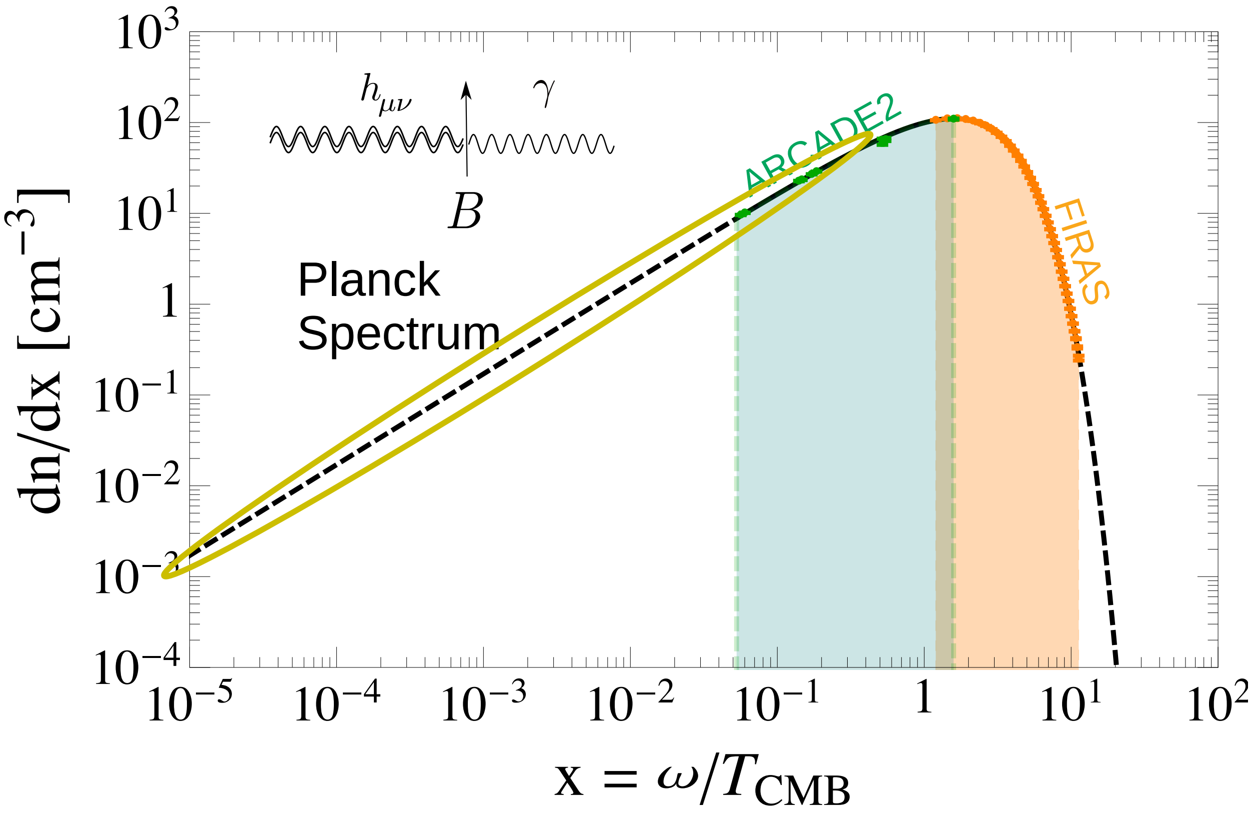

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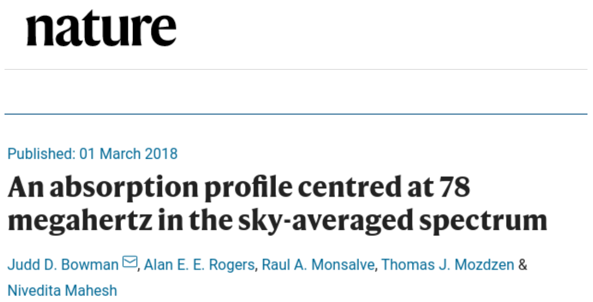

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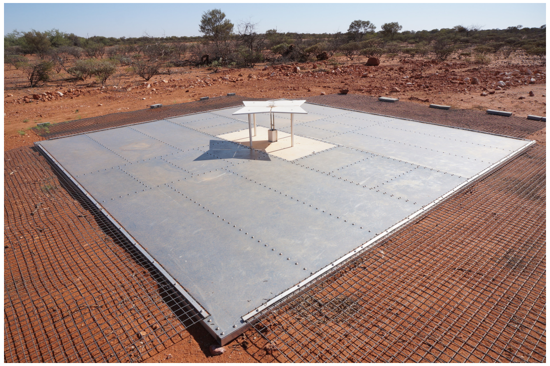

Rayleigh-Jeans tail

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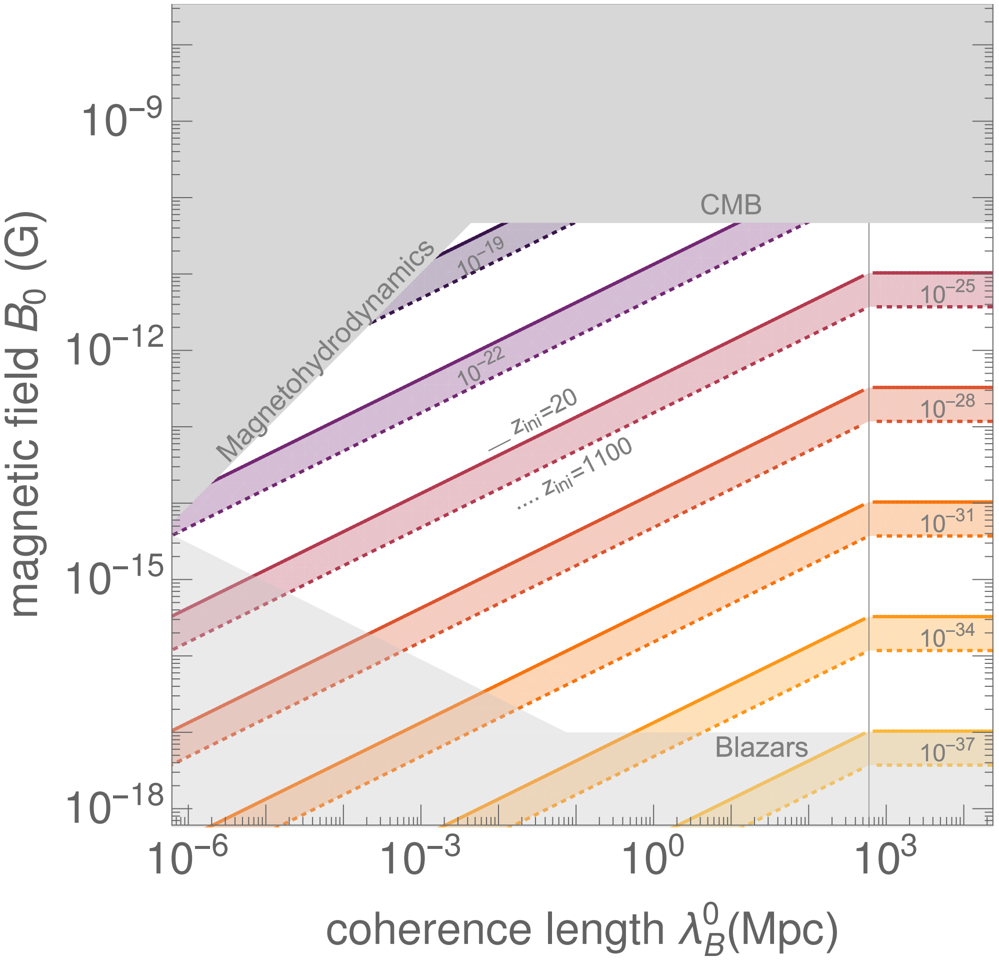
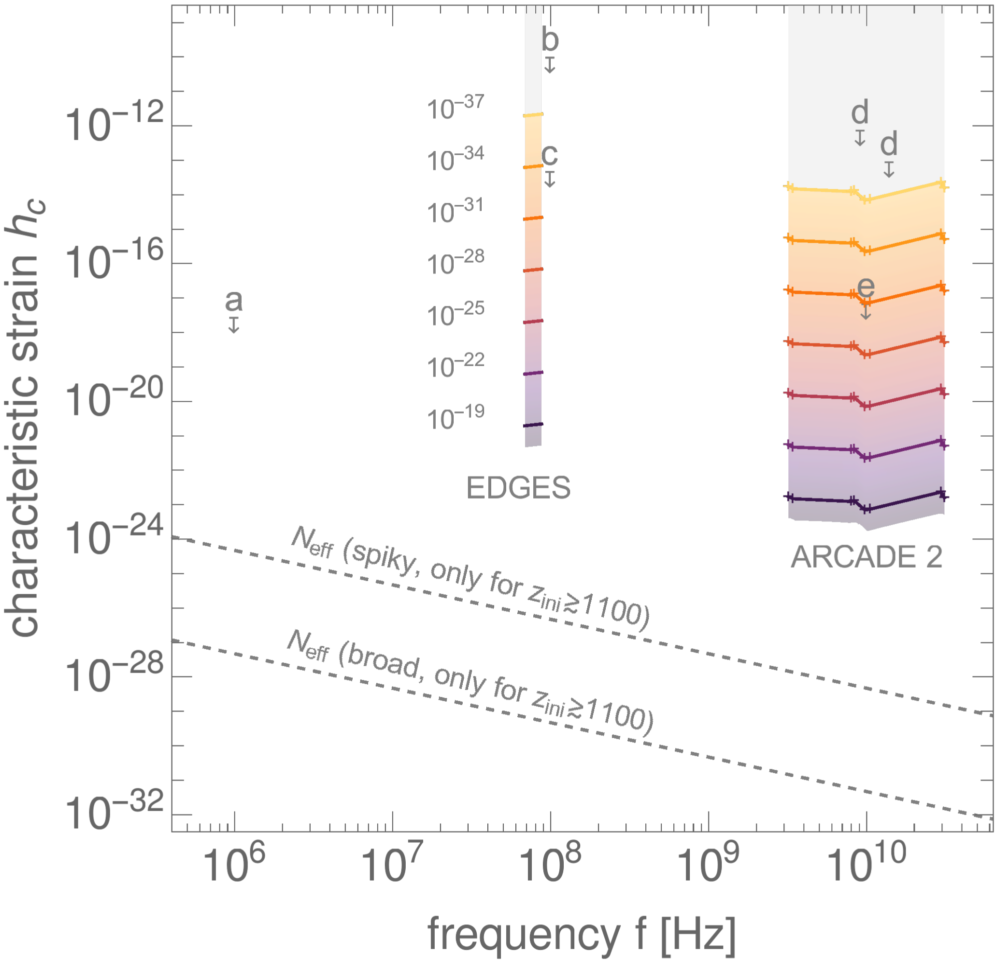
- They may conceivably push these bounds below the Neff constraint.

Upper bounds on stochastic gravitational waves



Domcke,CGC 2020



existing laboratory bounds from

a) superconducting parametric converter Reece et al '84

b) waveguide Cruise Ingley '06

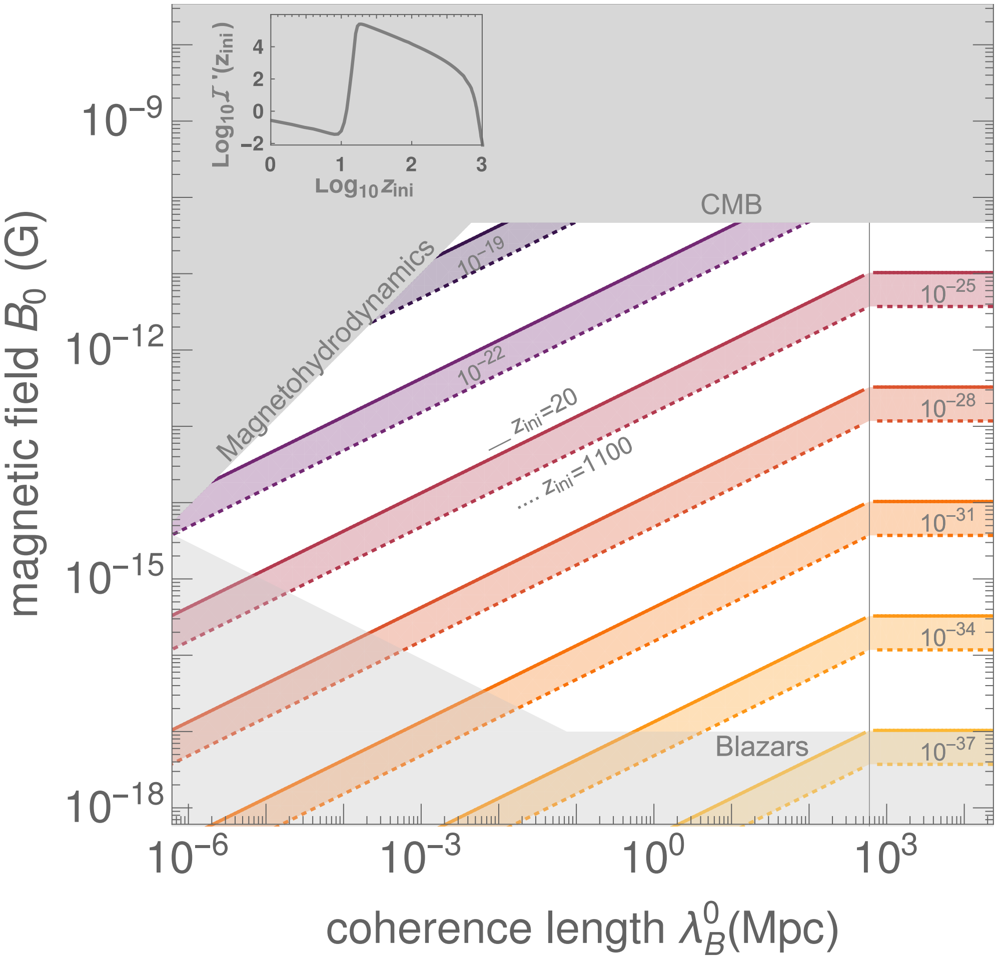
c) 0.75 m interferometer Akutsu '08

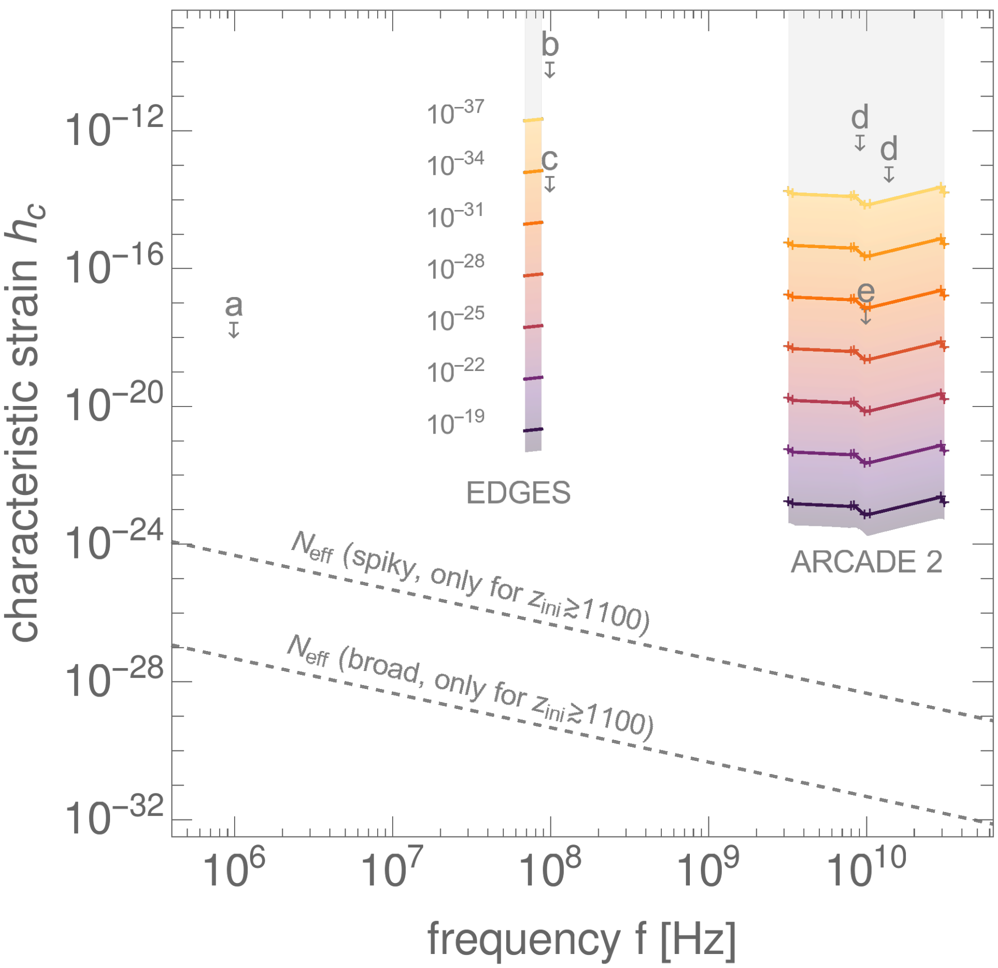
d) magnon detector Ito, Soda '04

e) magnetic conversion detector Cruise et al '12

Upper bounds on stochastic gravitational waves

Domcke,CGC 2020





Conclusions

- The Gertsenshtein effect during the dark ages provides a powerful way to probe GWs in the MHz-GHz range from distortions of the Rayleigh-Jeans CMB tail.

- With upcoming advances in 21cm astronomy targeting precisely this frequency range with increasing accuracy, it becomes conceivable to push the limits derived from radio telescopes below the cosmological bound constraining the total energy in GWs.

Conclusions

- The Gertsenshtein effect during the dark ages provides a powerful way to probe GWs in the MHz-GHz range from distortions of the Rayleigh-Jeans CMB tail.

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Thank you for your attention

Wave equation

$$\left(\Box + \omega_{\rm pl}^2/c^2\right) A_\lambda = -B\partial_\ell h_\lambda \,, \quad \Box h_\lambda = \kappa^2 B \partial_\ell A_\lambda \,,$$

Solution

$$\psi(t,\ell) \equiv \begin{pmatrix} \sqrt{\mu}\; A_\lambda \\ \frac{1}{\kappa}\, h_\lambda \end{pmatrix} = e^{-i\omega t} e^{iK\ell} \psi(0,0)\,,$$

$$K = \begin{pmatrix} \frac{\mu}{c}\sqrt{\omega^2 + \left(\frac{\kappa B}{1+\mu}\right)^2} & -i\frac{\sqrt{\mu}\,\kappa B}{1+\mu} \\ i\frac{\sqrt{\mu}\,\kappa B}{1+\mu} & \frac{1}{c}\sqrt{\omega^2 + \left(\frac{\kappa B}{1+\mu}\right)^2} \end{pmatrix} .$$

Conversion rate

$$\langle \Gamma_{g\leftrightarrow\gamma} \rangle = \frac{c\,|K_{12}|\;\ell_{\rm osc}}{2\Delta\ell} \,.$$

$$\ell_{\rm osc}^{-1} \quad = \quad \sqrt{\omega^2 (1-\mu)^2/c^2 + \kappa^2 B^2}/2.$$

$$\mathcal{P} \equiv \int \quad \langle \Gamma_{g\leftrightarrow\gamma} \rangle dt = \int^{z_{\rm ini}} \frac{\langle \Gamma_{g\leftrightarrow\gamma} \rangle}{(1+z)\,H} dz\,,$$

CMB distortions

$$\delta f_\gamma(\omega_0, T_0) = \big(f_g(\omega_{\rm ini}, T_{\rm ini}) - f_{\rm eq}\big)\,\mathcal{P} + \mathcal{O}(\mathcal{P}^2)\,,$$

$$\frac{\delta f_\gamma}{f_\gamma}(\omega_0, T_0) = \frac{\pi^4}{15}\left(\frac{T}{\omega}\right)^3 \mathcal{P}\,\frac{\Omega_{\rm GW}}{\Omega_\gamma} \quad \text{for } \omega \ll T$$

$$h_c = \left(\frac{3H_0^2}{4\pi^2}\Omega_{\rm GW} f^{-2}\right)^{1/2} .$$