Synergy between gravitational waves and axions in the CMB

Camilo A. Garcia Cely

Alexander von Humboldt Fellow

Based on

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,†]
[1]*Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany*
[2]*Theoretical Physics Department, CERN, 1 Esplanade des Particules, CH-1211 Geneva 23, Switzerland*
[3]*Institute of Physics, Laboratory for Particle Physics and Cosmology (LPPC),*
École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

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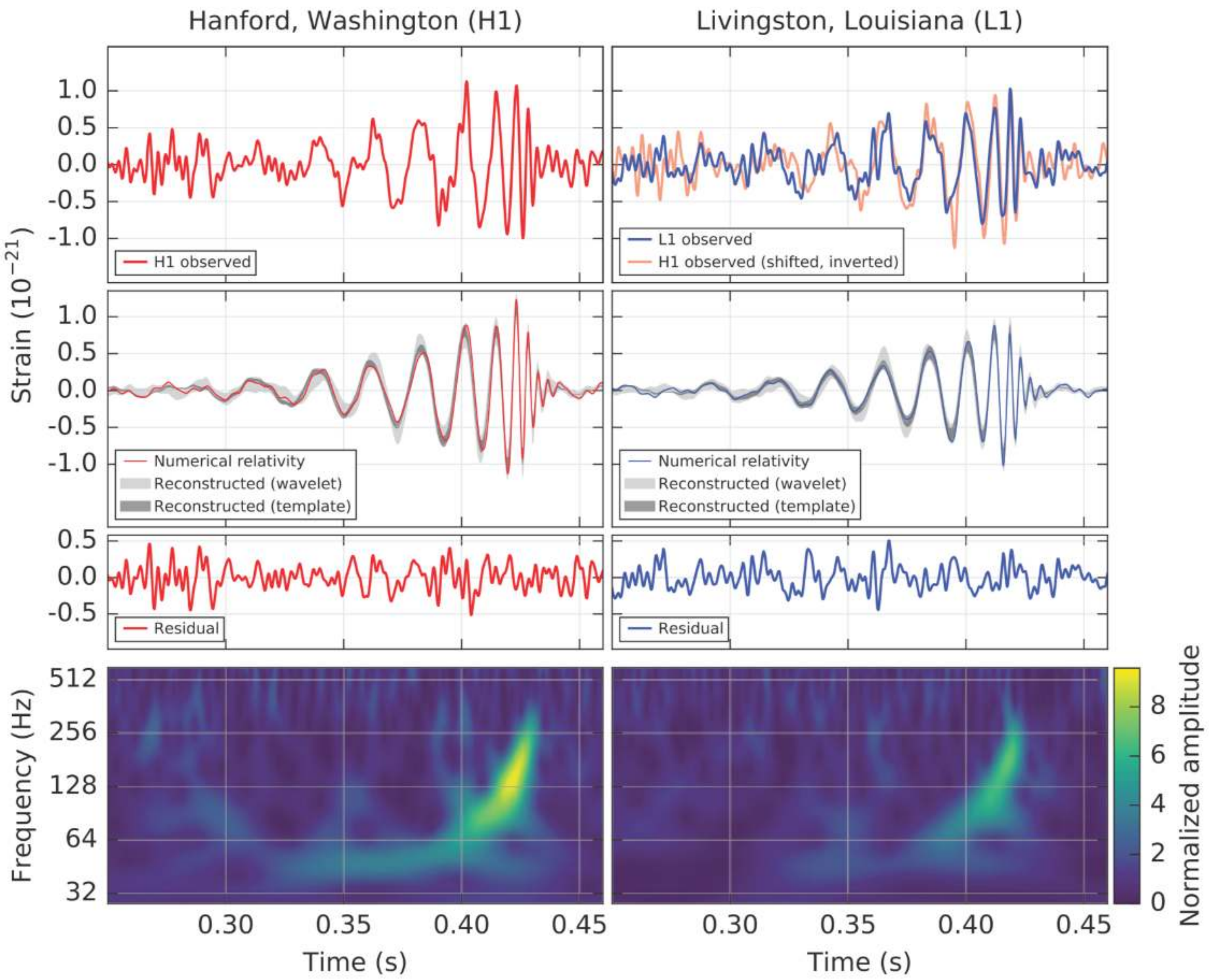
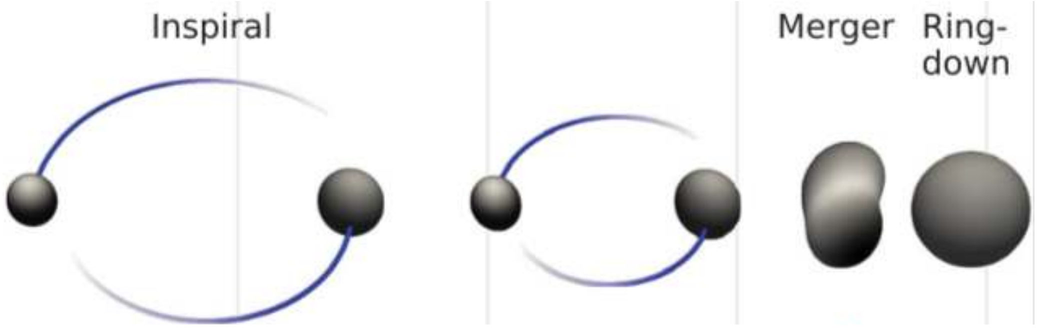
Gravitational Waves

- Predicted by Poincaré (1905)
- Einstein provided a firm theoretical background for them (1916)

$$\Box h_{\mu\nu} = -16\pi G T_{\mu\nu}$$

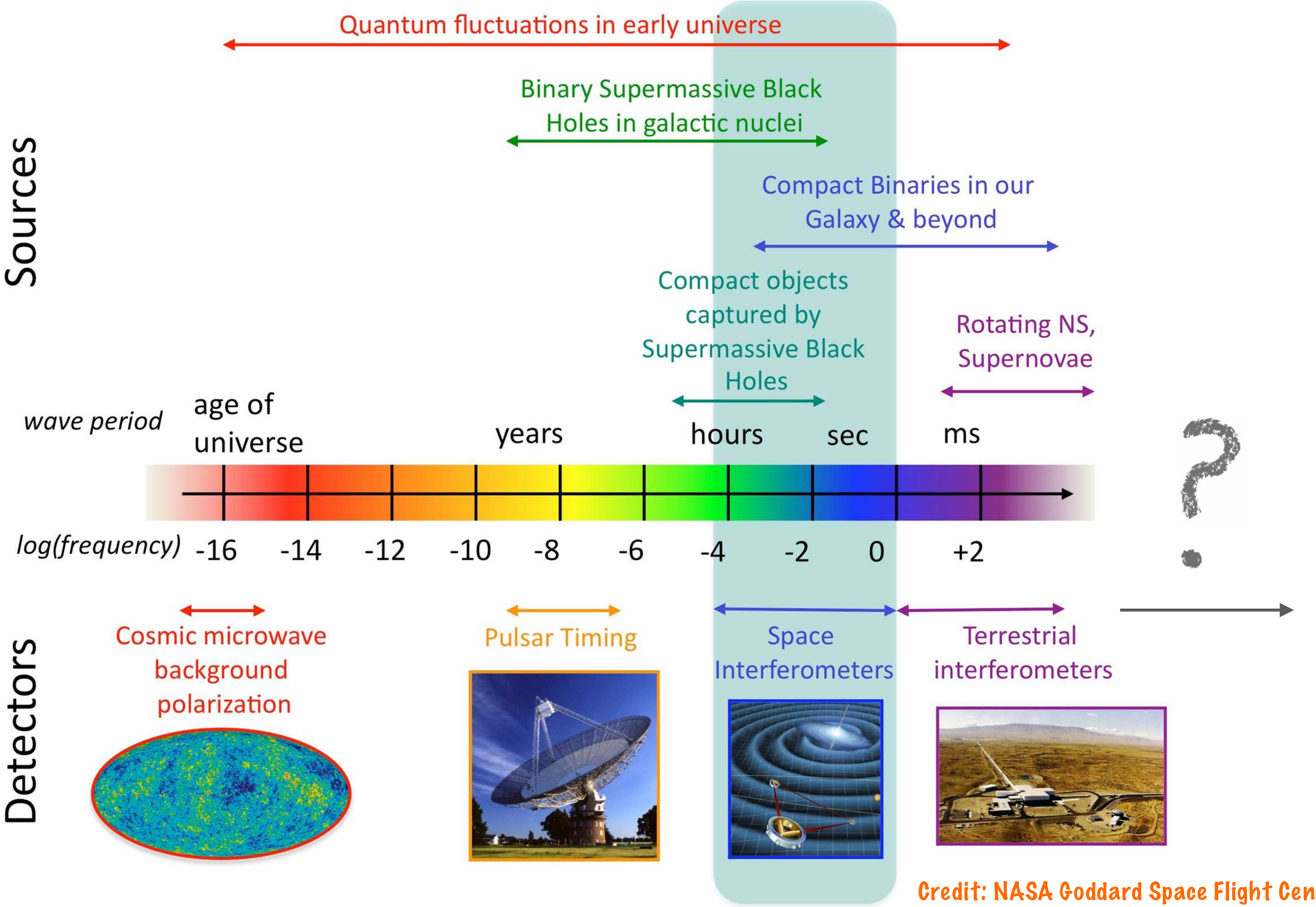
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016





Terrestrial interferometers

Gravitational Wave Spectrum



Sources

Quantum fluctuations in early universe

Binary Supermassive Black Holes in galactic nuclei

Compact Binaries in our Galaxy & beyond

Compact objects captured by Supermassive Black Holes

Rotating NS, Supernovae

wave period age of universe — years — hours — sec — ms

log(frequency) -16 -14 -12 -10 -8 -6 -4 -2 0 +2

?

Detectors

Cosmic microwave background polarization

Pulsar Timing

Space Interferometers

Terrestrial interferometers

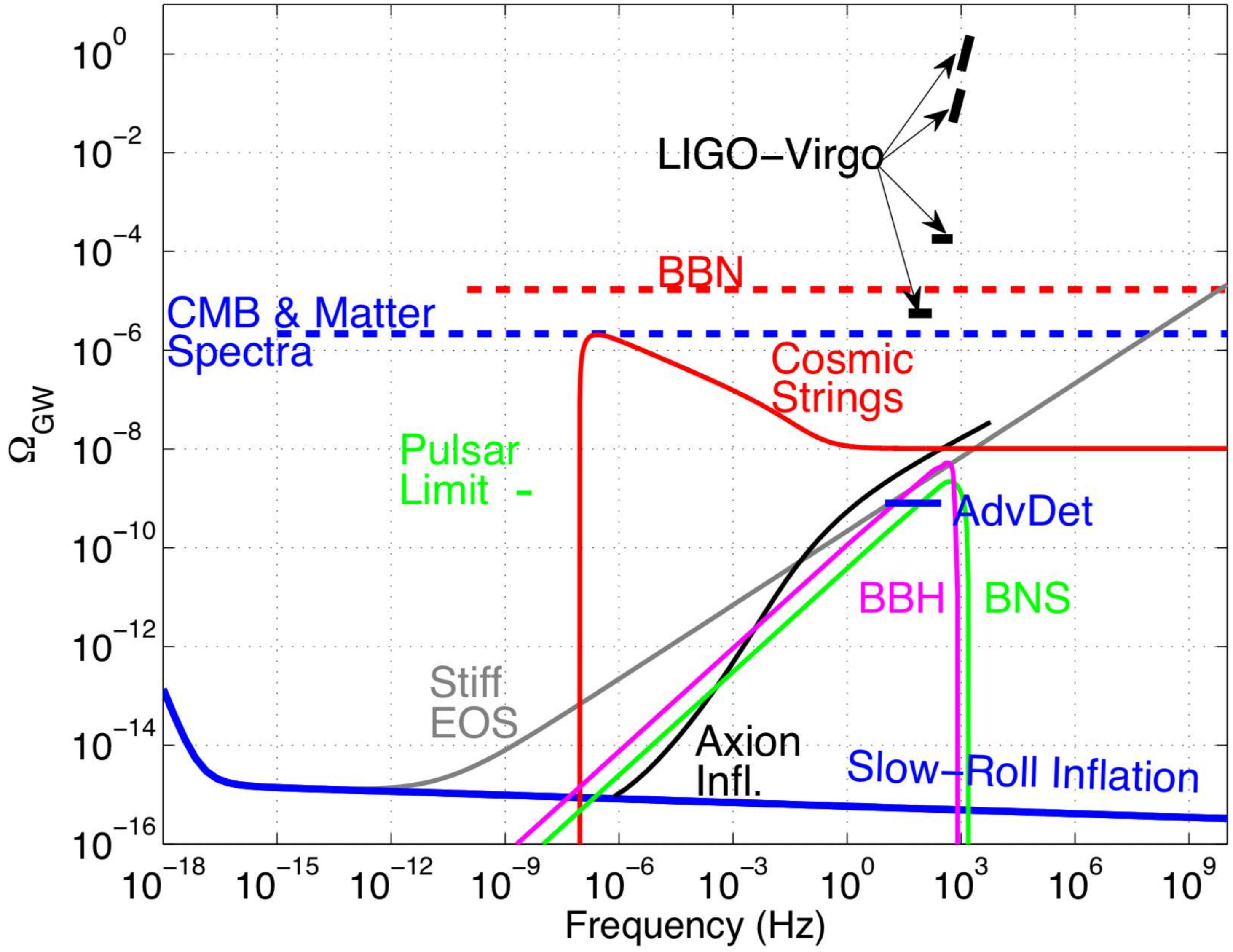
Credit: NASA Goddard Space Flight Center

Camilo A. Garcia Cely

Gravitational Wave Spectrum

what about high frequencies?

LIGO - VIRGO, 2014



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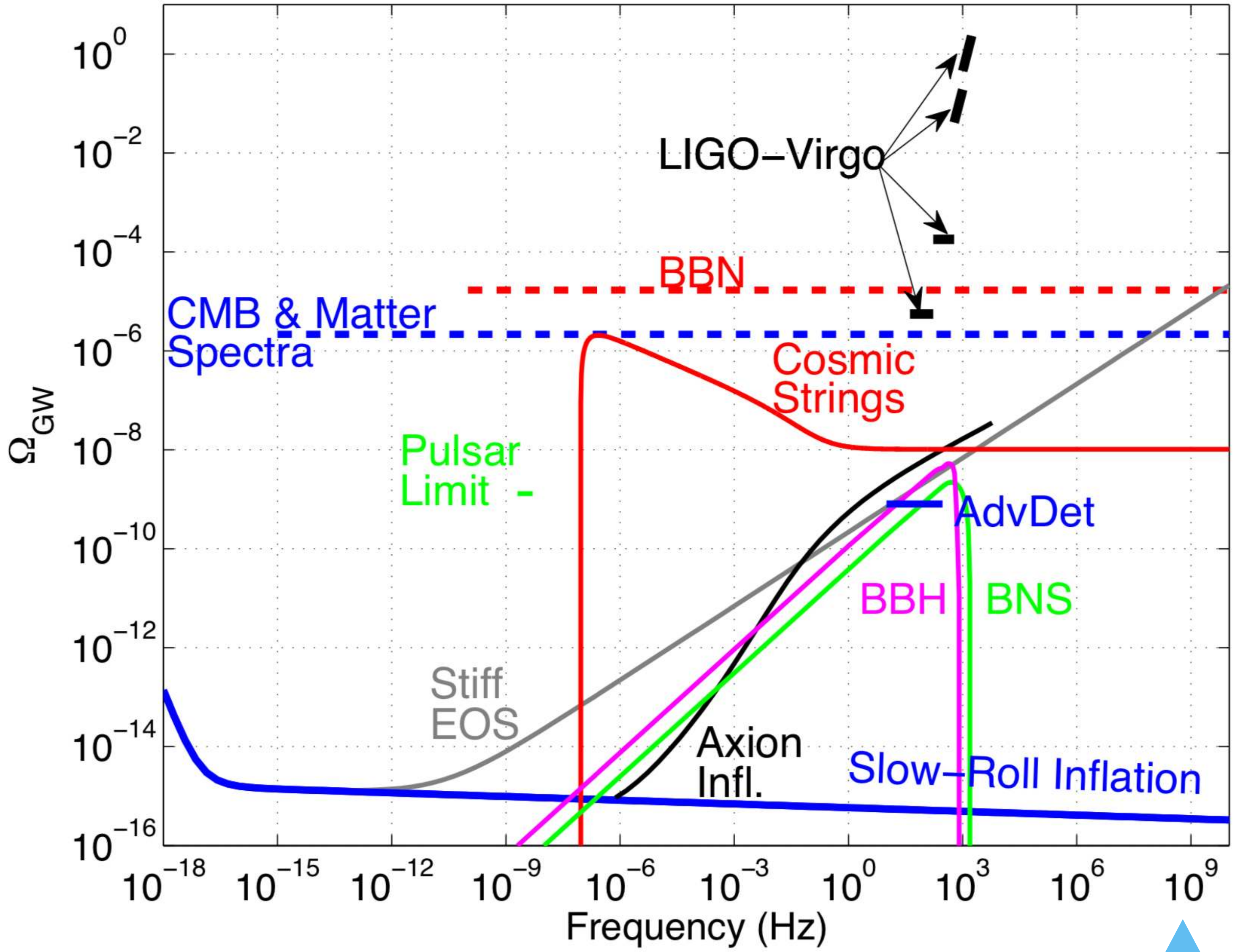

Radio and TeV astronomy

Domcke, CGC 2021

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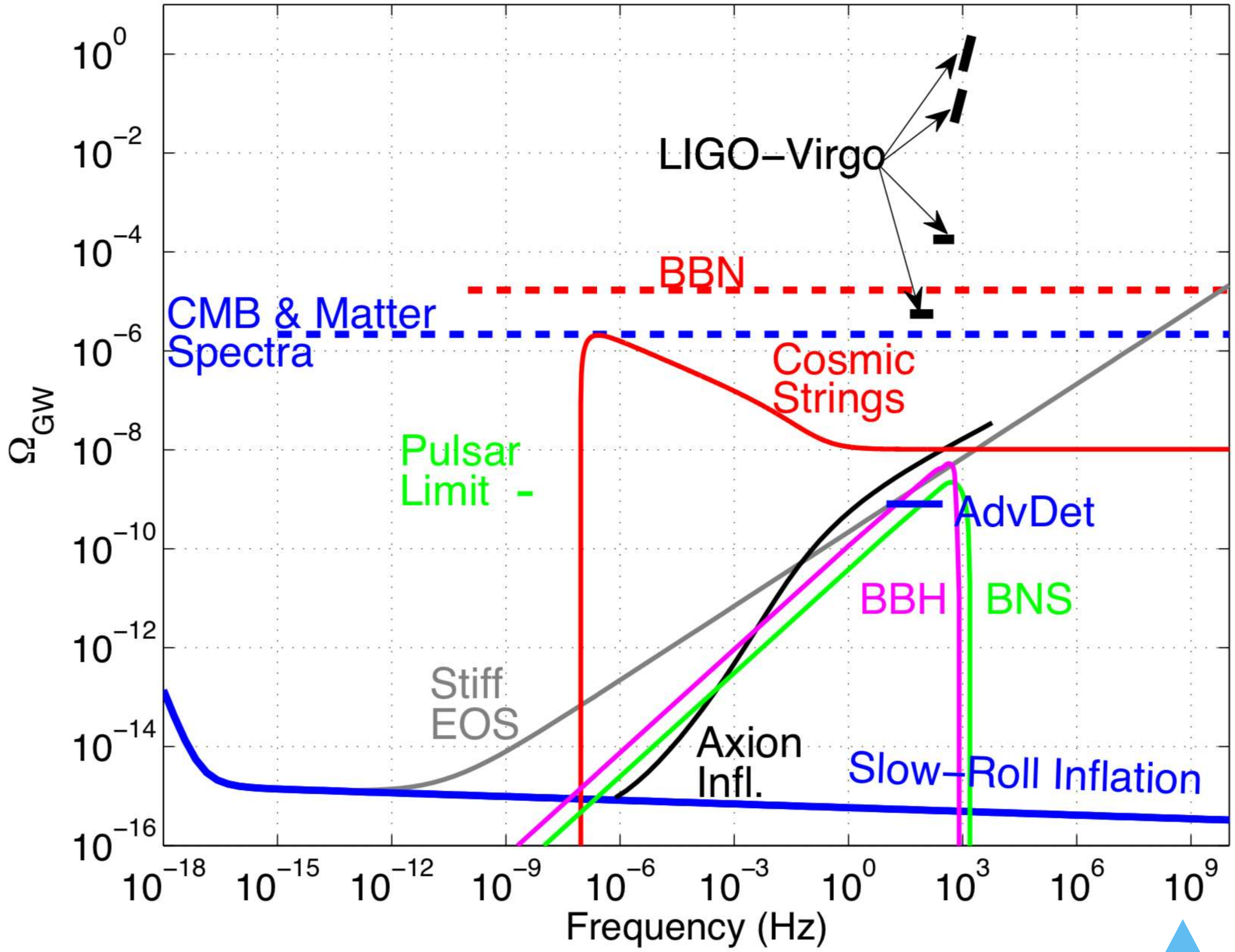

Cosmological constraints on radiation energy N_{eff}

Radio and TeV astronomy

Domcke, CGC 2021

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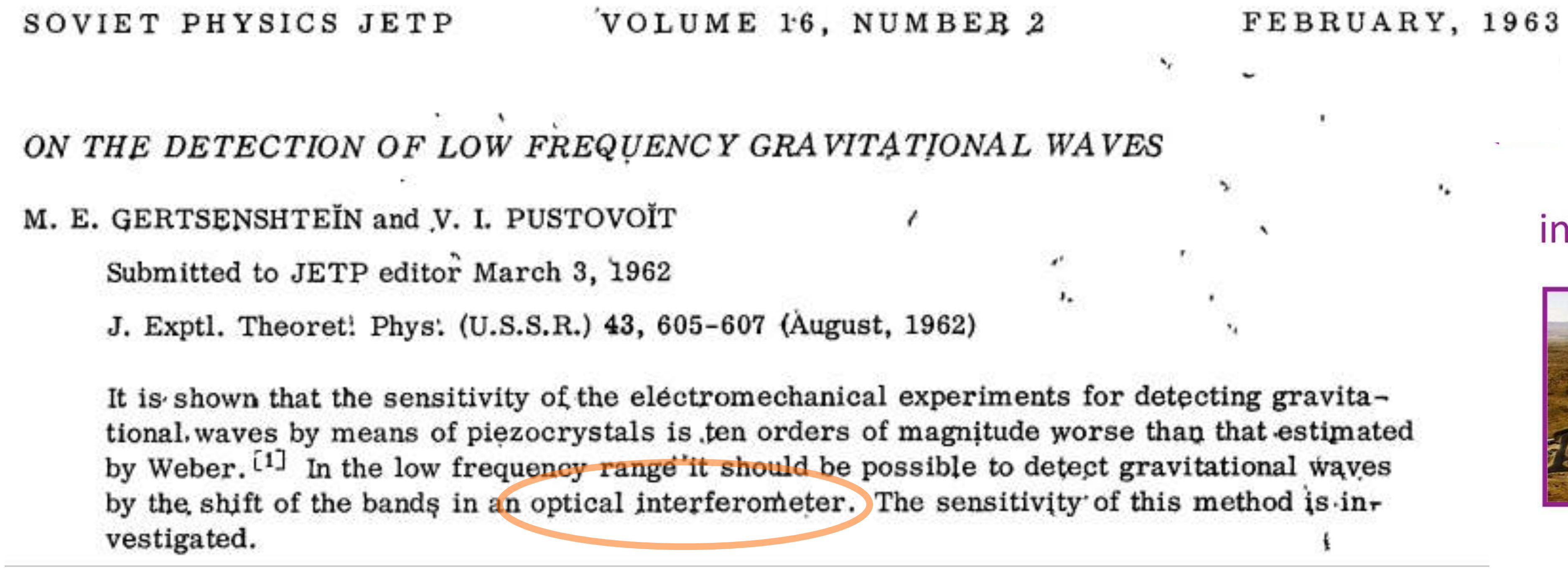
Gravitational Waves
and the Gertsenhstein Effect

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.

Terrestrial interferometers

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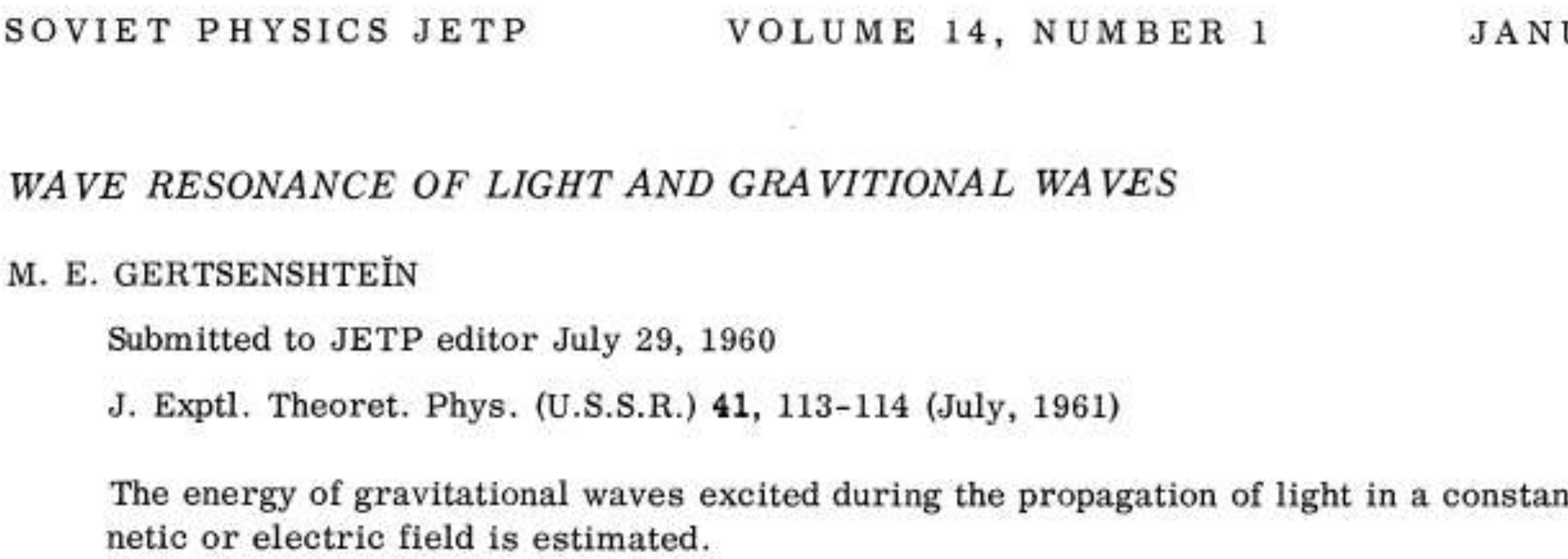


SOVIET PHYSICS JETP VOLUME 14, NUMBER 1 JANUARY, 1962

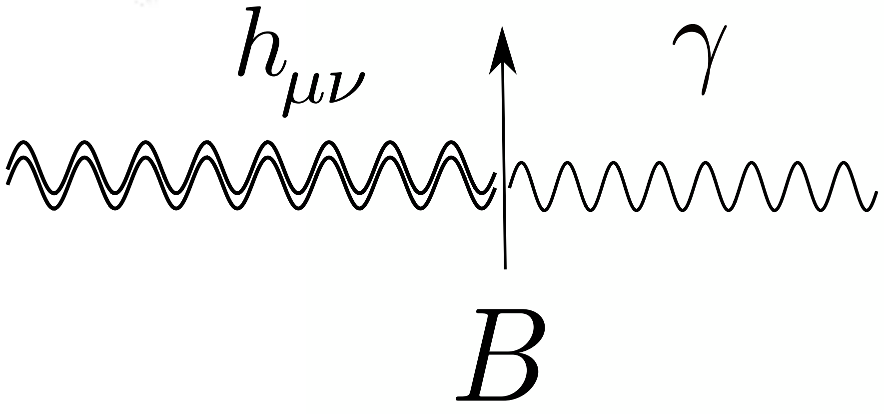
WAVE RESONANCE OF LIGHT AND GRAVITIONAL WAVES

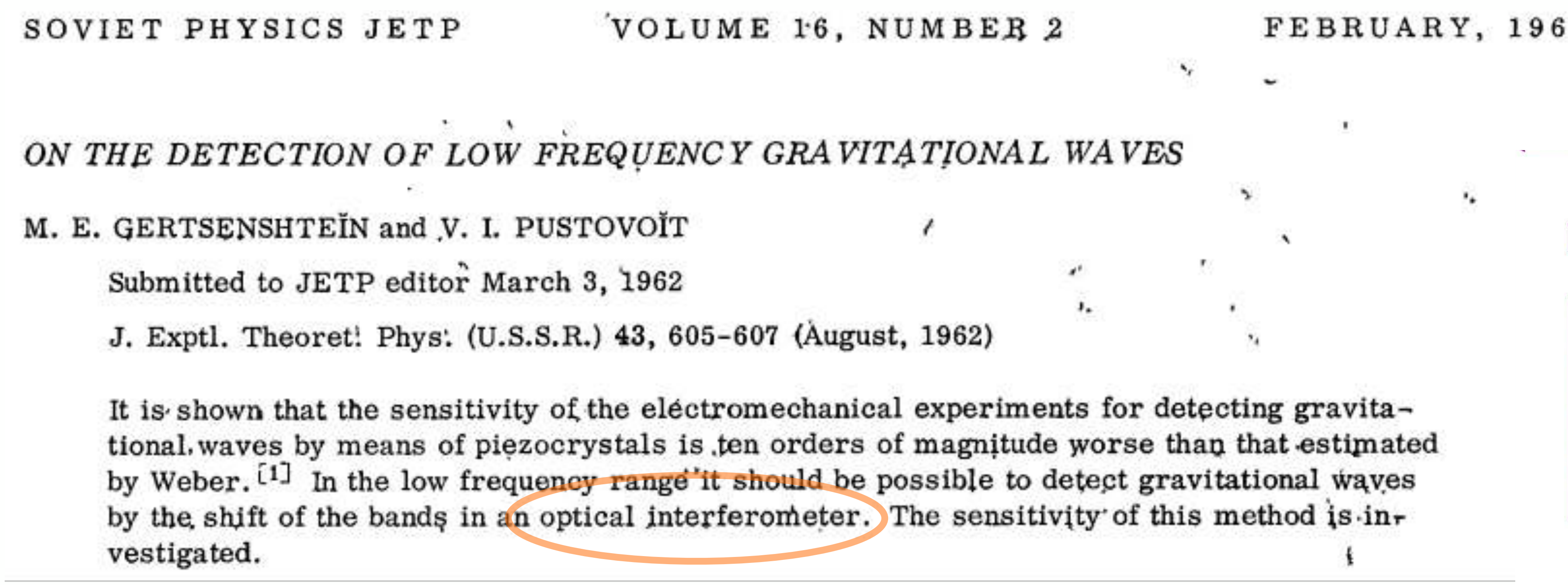
M. E. GERTSENSHTEĬN

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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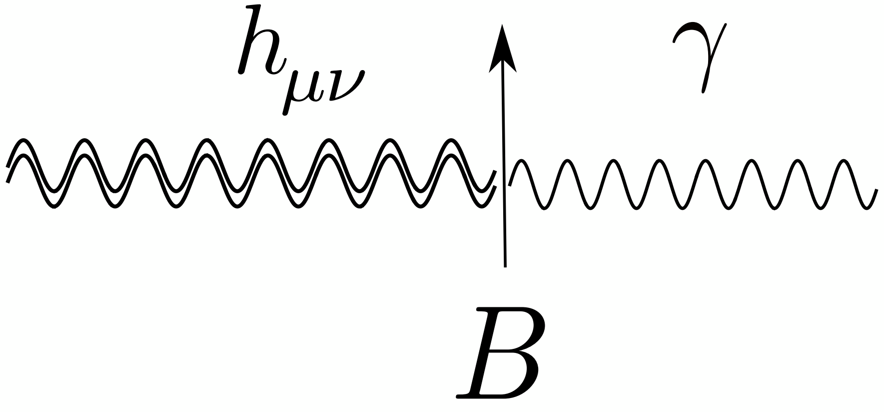

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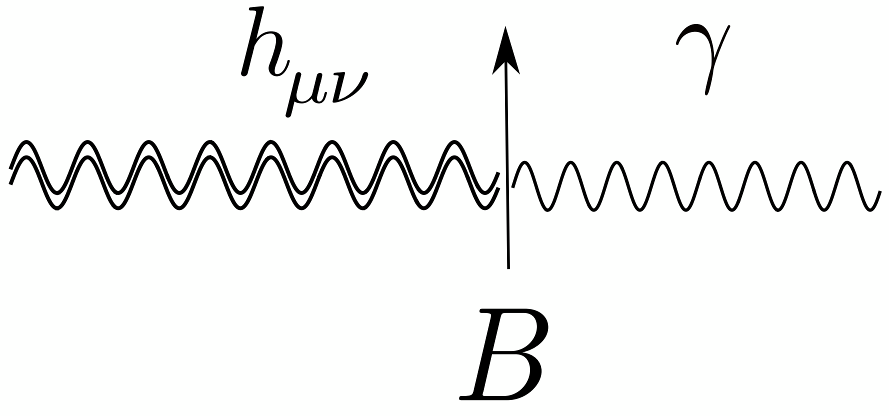
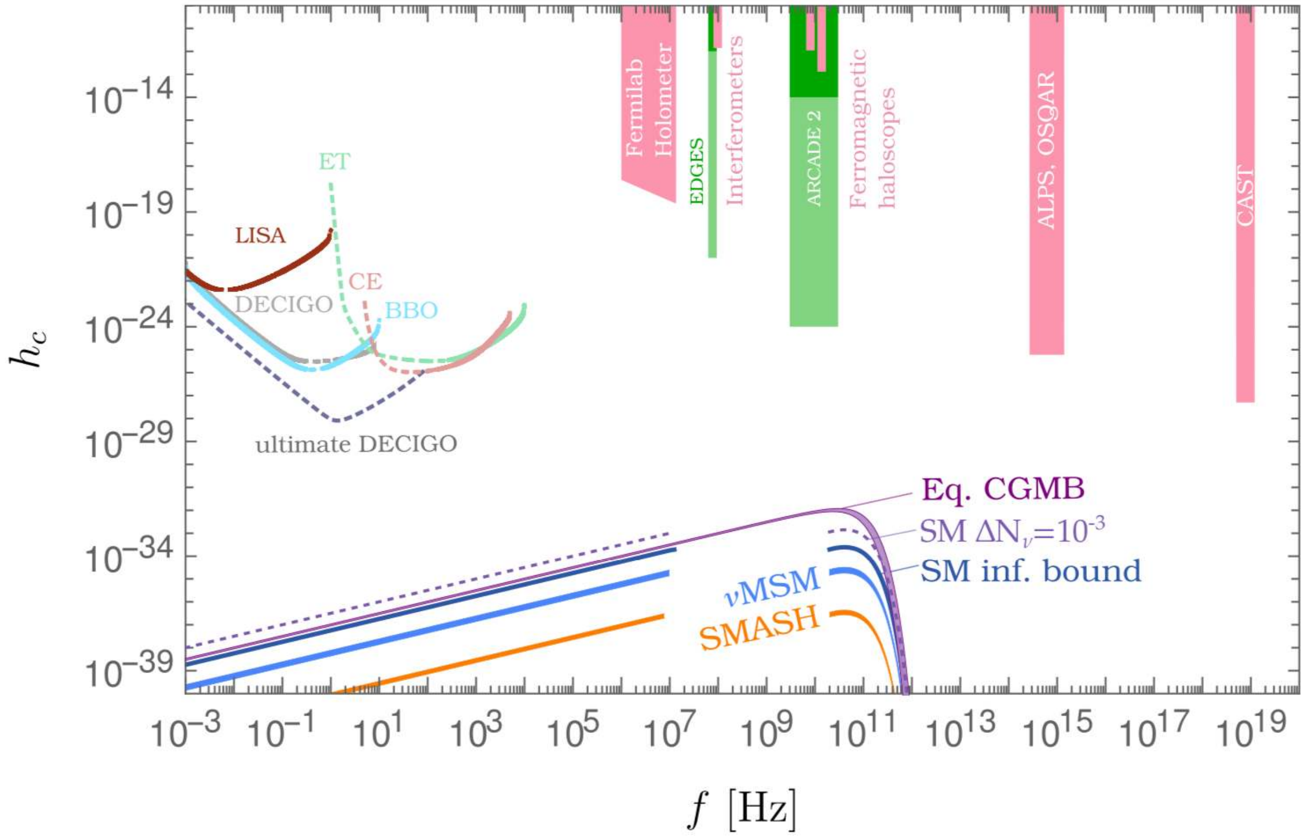


Ringwald, Jan Schütte-Engel, Tamarit 2011.04731



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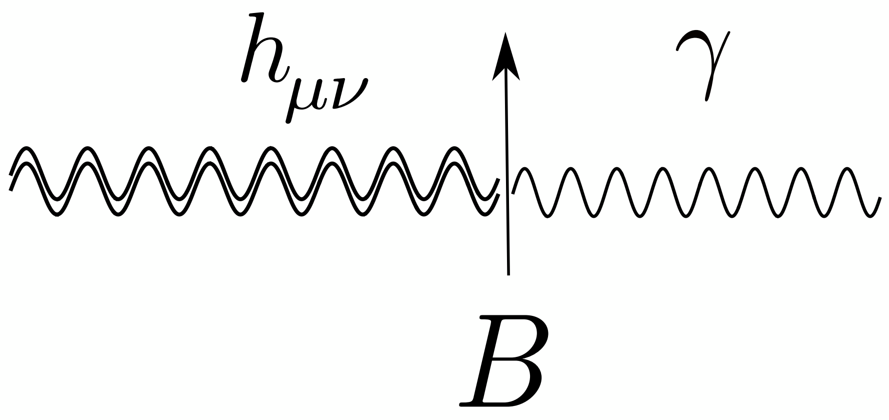

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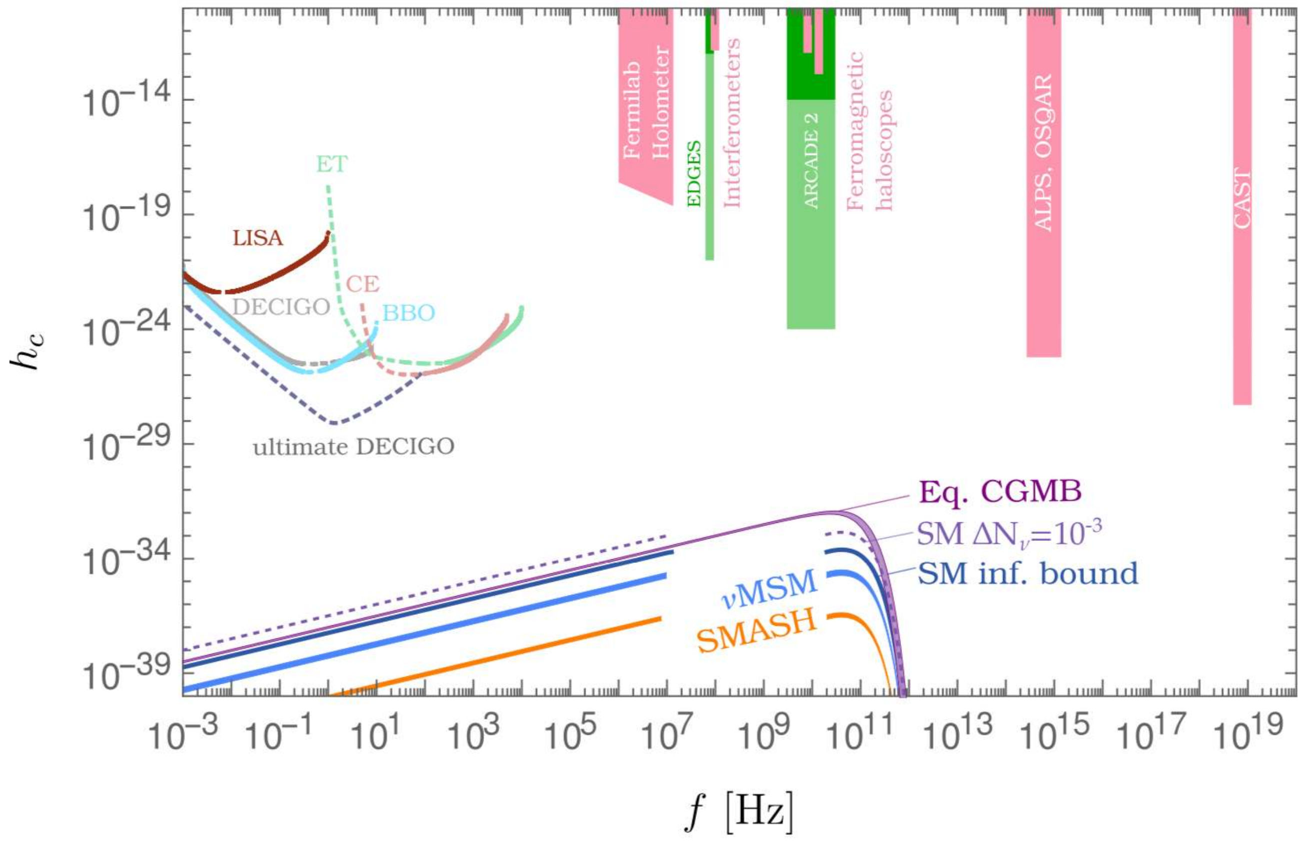

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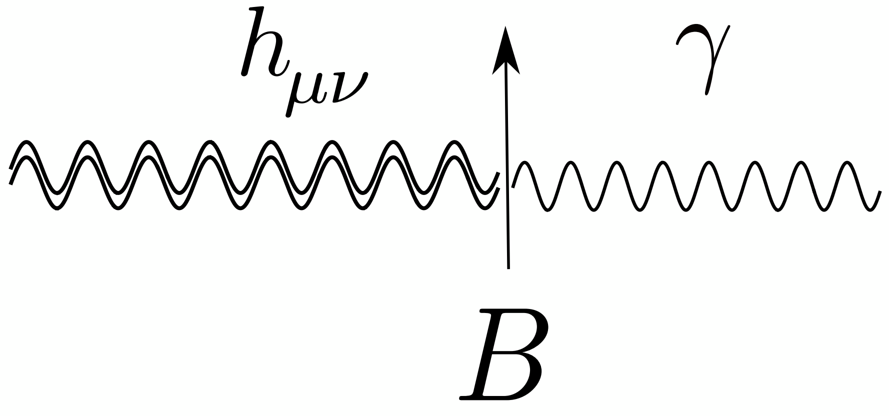

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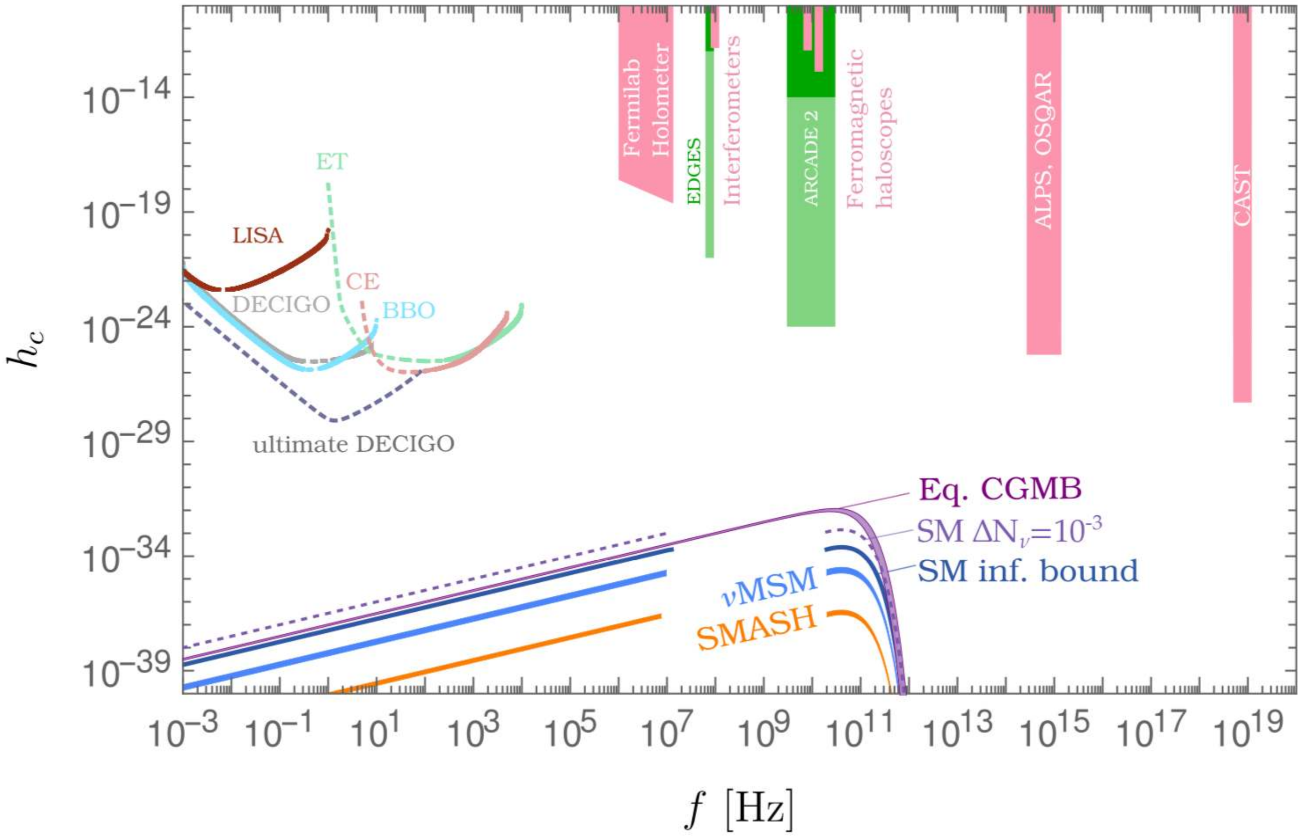
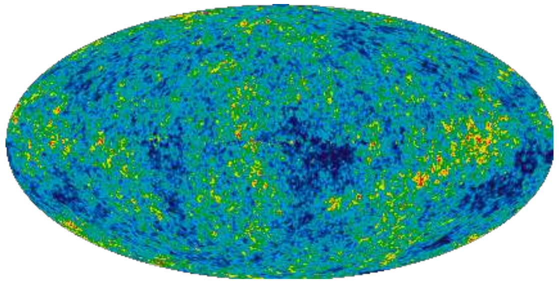


- Distortions of the CMB

Domcke, CGC 2021



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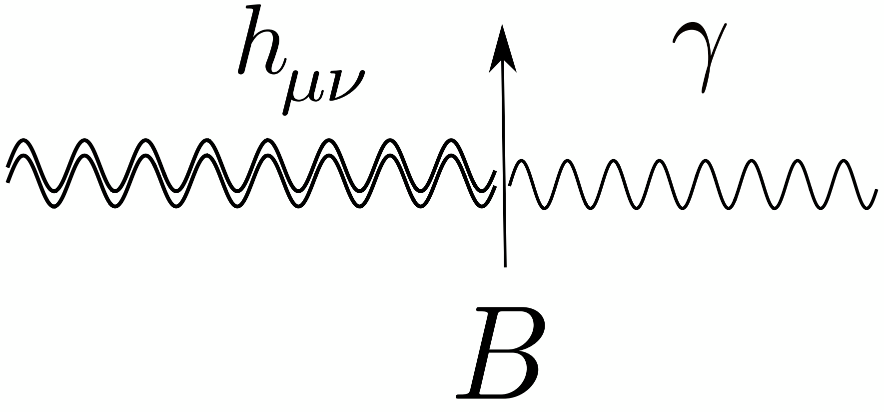
Domcke, CGC 2021

Dolgov, Ejlli 2012

Pshirkov, Baskaran 2009

Chen 1995



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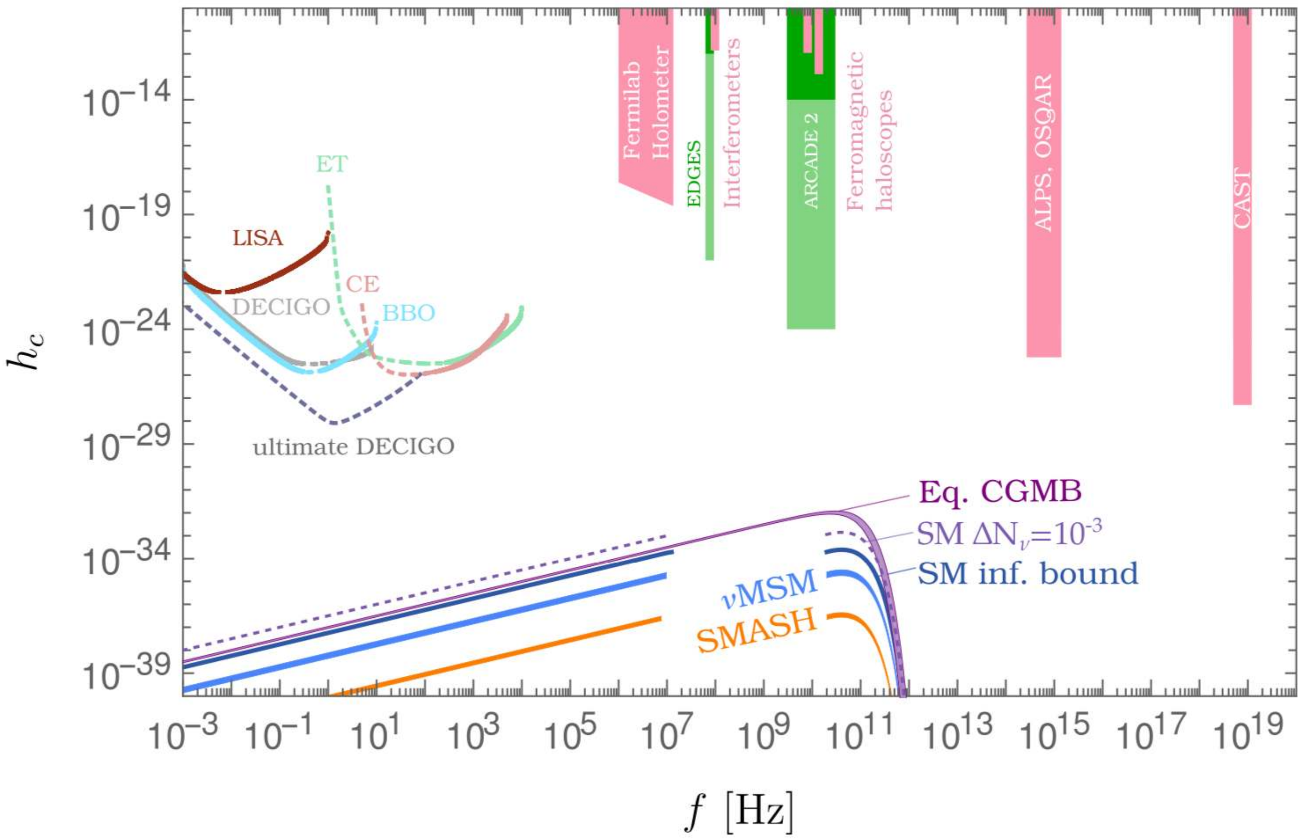
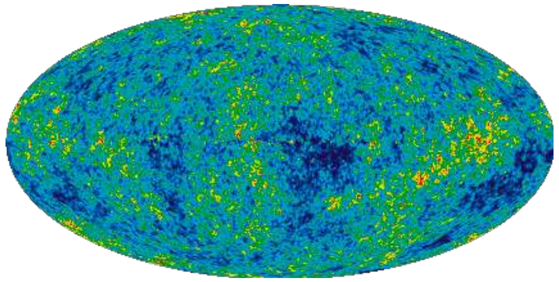
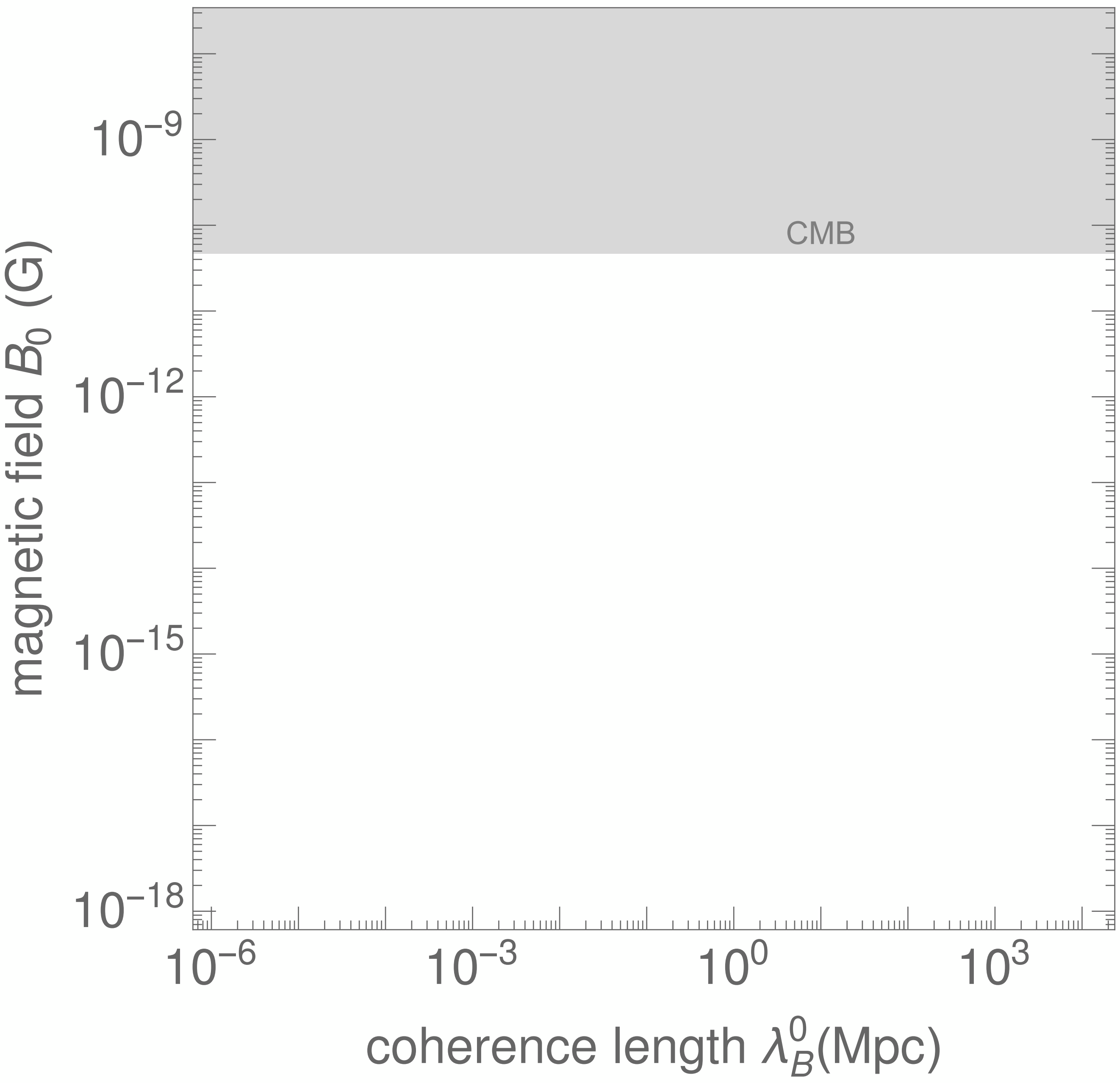


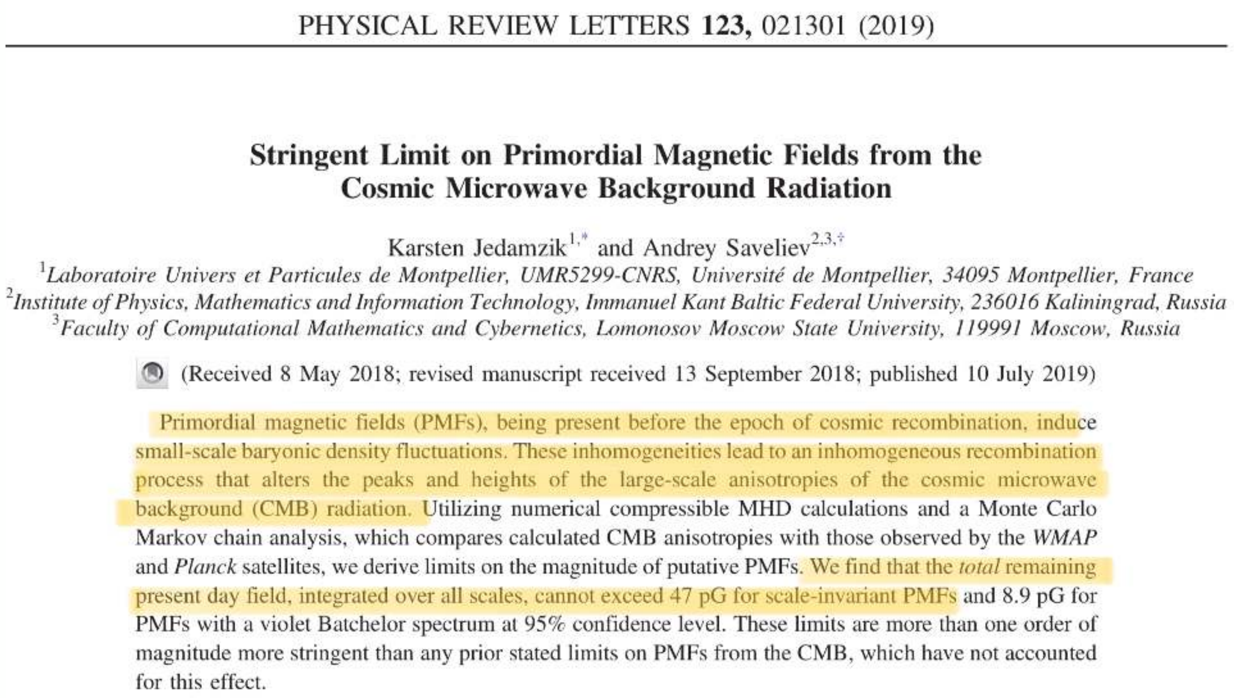


Cosmic magnetic fields and multi-messenger astronomy

Cosmic magnetic fields and multi-messenger astronomy

Domcke, CGC 2021





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*
[2]*Institute of Physics, Mathematics and Information Technology, Immanuel Kant Baltic Federal University, 236016 Kaliningrad, Russia*
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(Received 8 May 2018; revised manuscript received 13 September 2018; published 10 July 2019)

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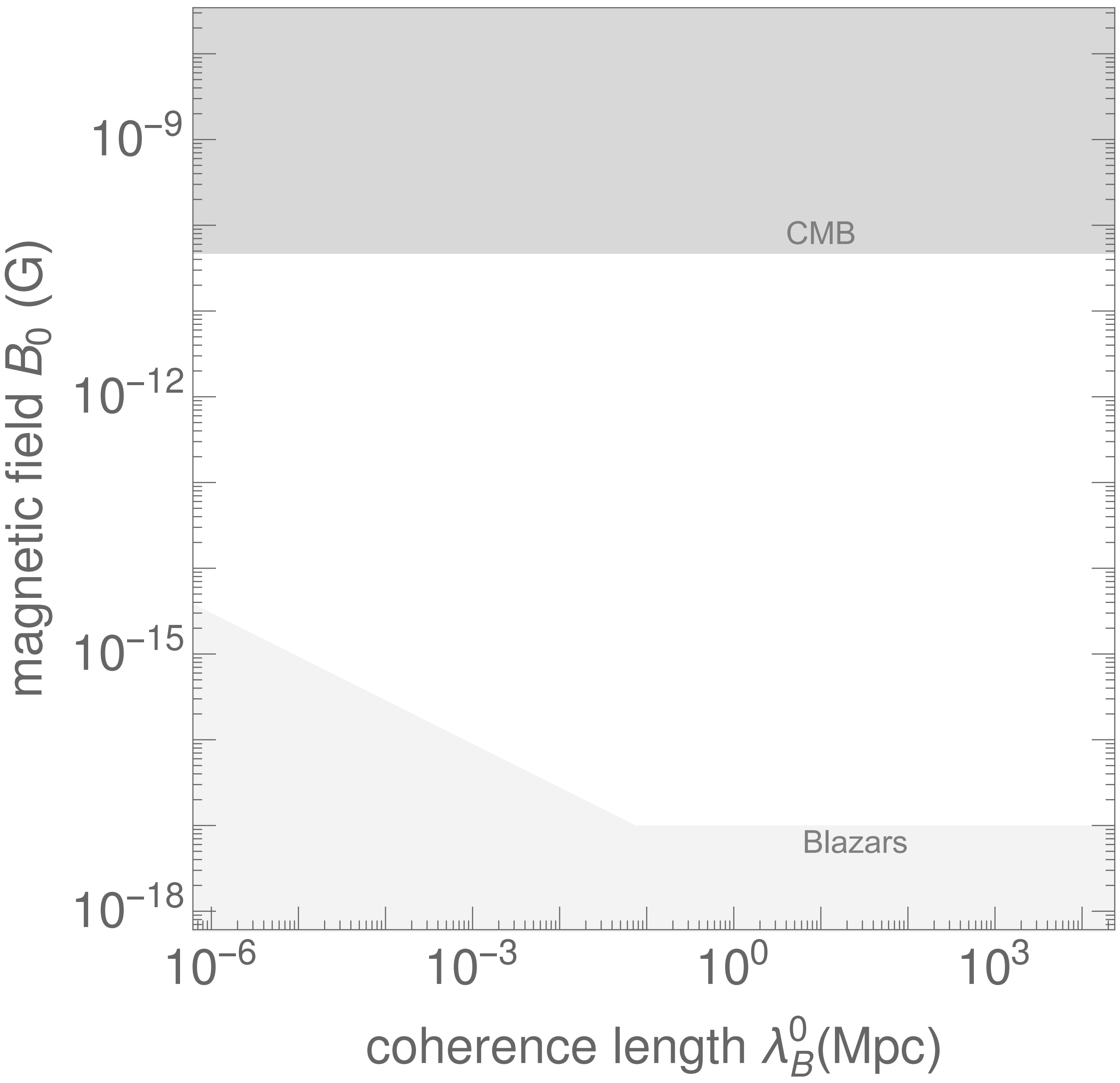

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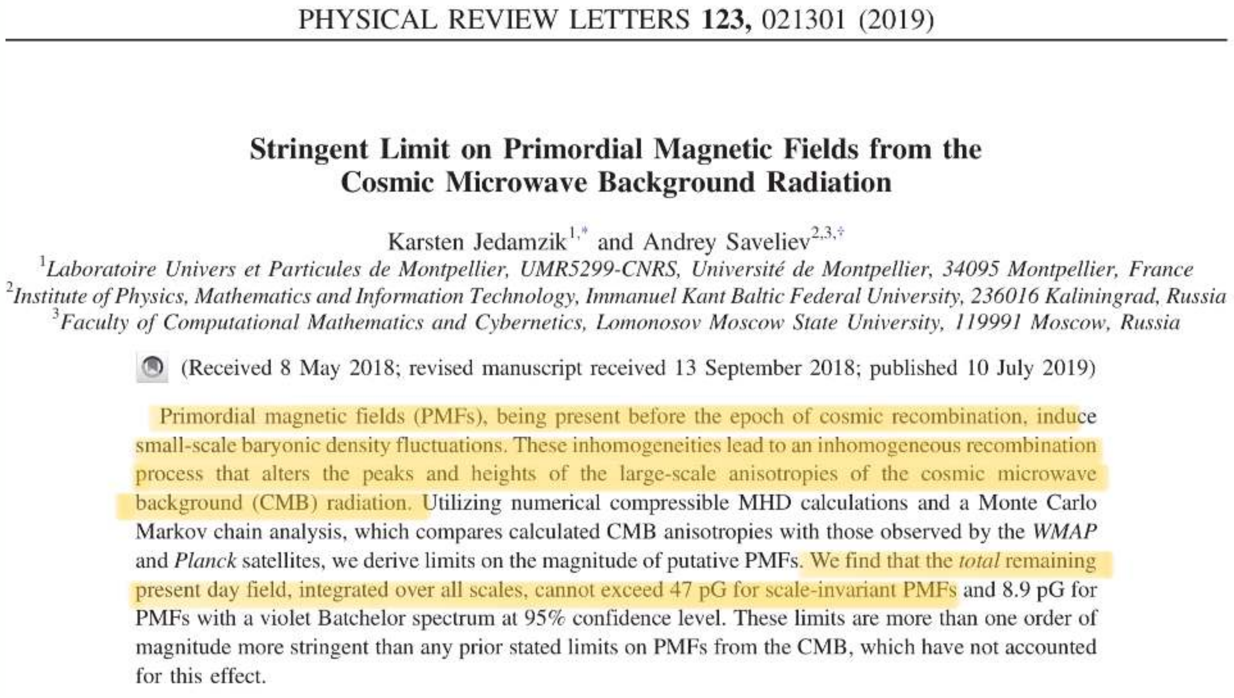

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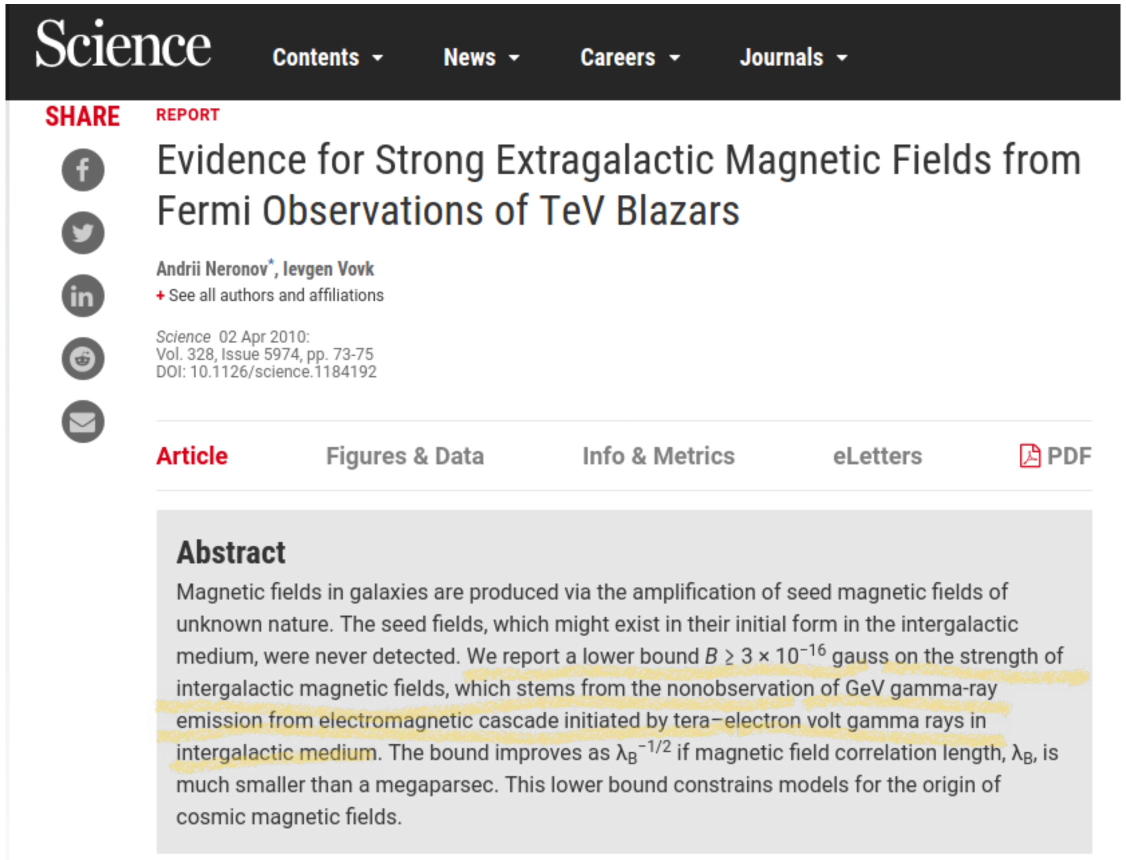

REPORT

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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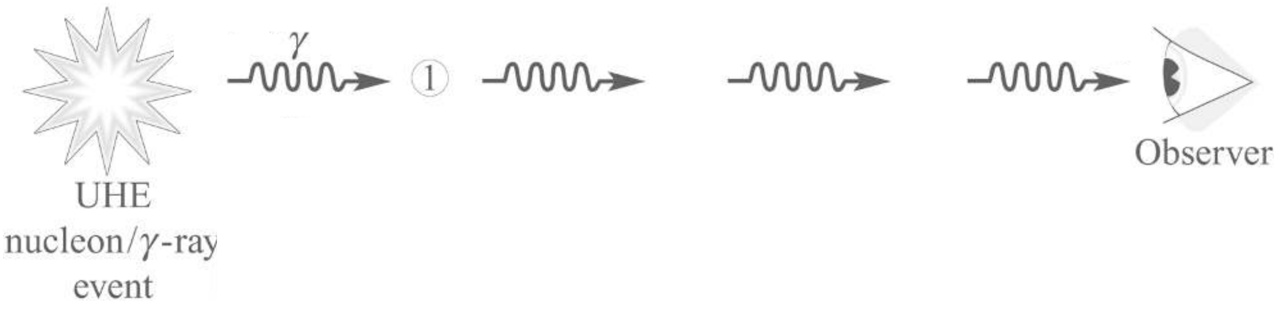
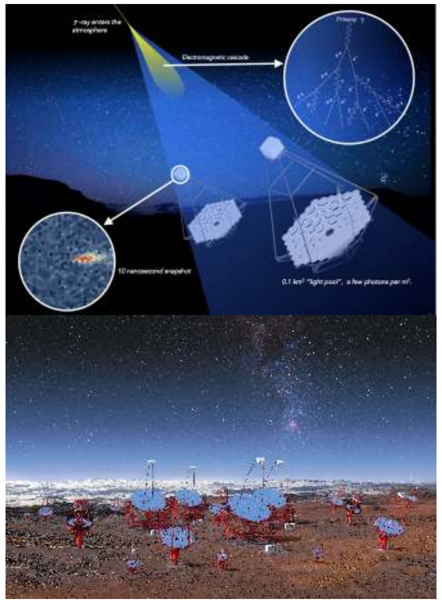
Synergy with TeV γ ray observatories

Kronberg , 2016
Cambridge University Press





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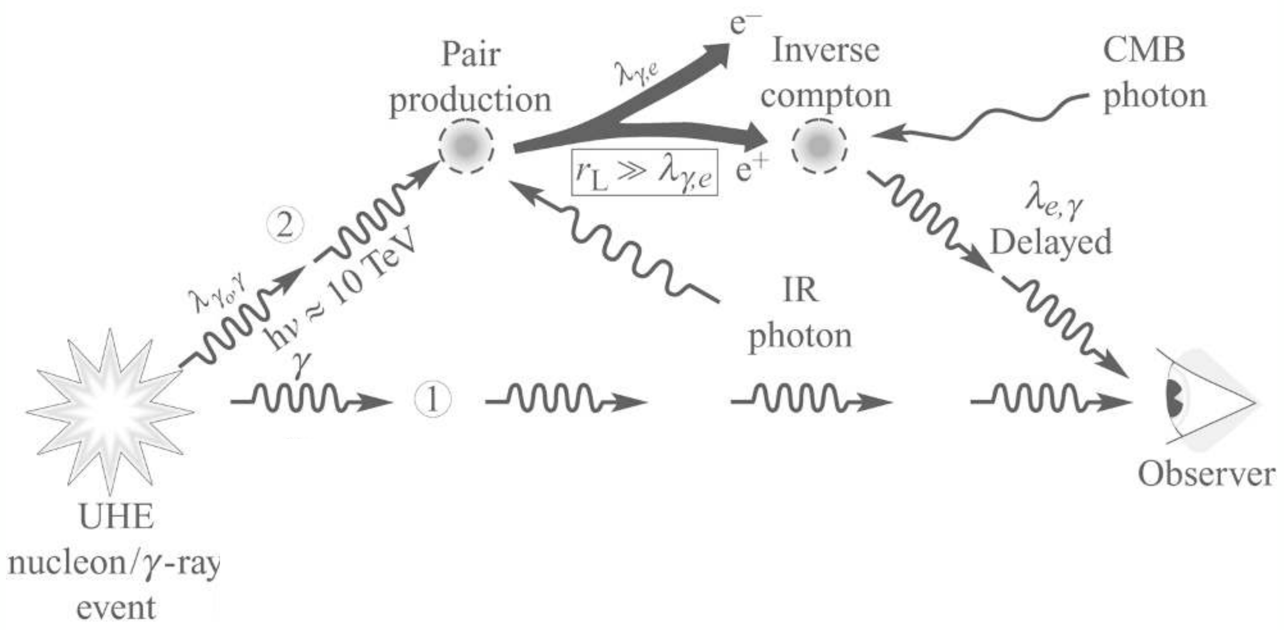
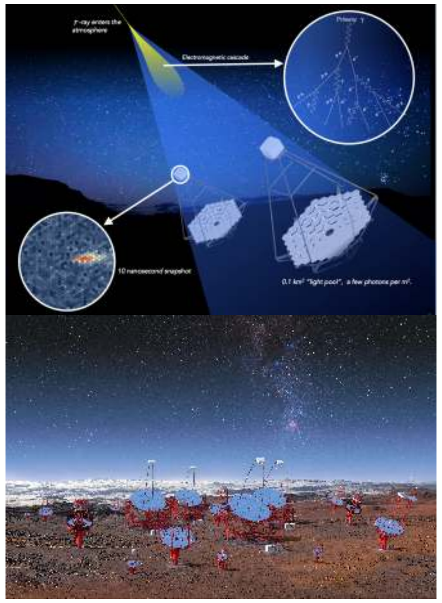

High energy $h\nu$ –e^+e^- cascades in the intergalactic medium



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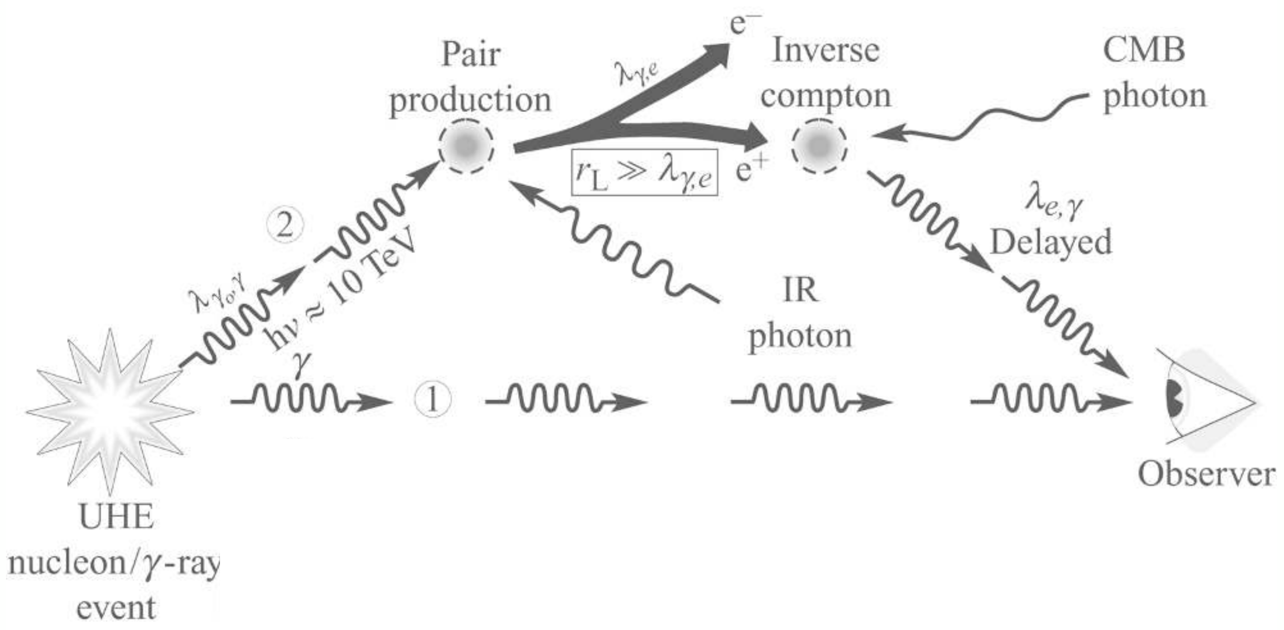

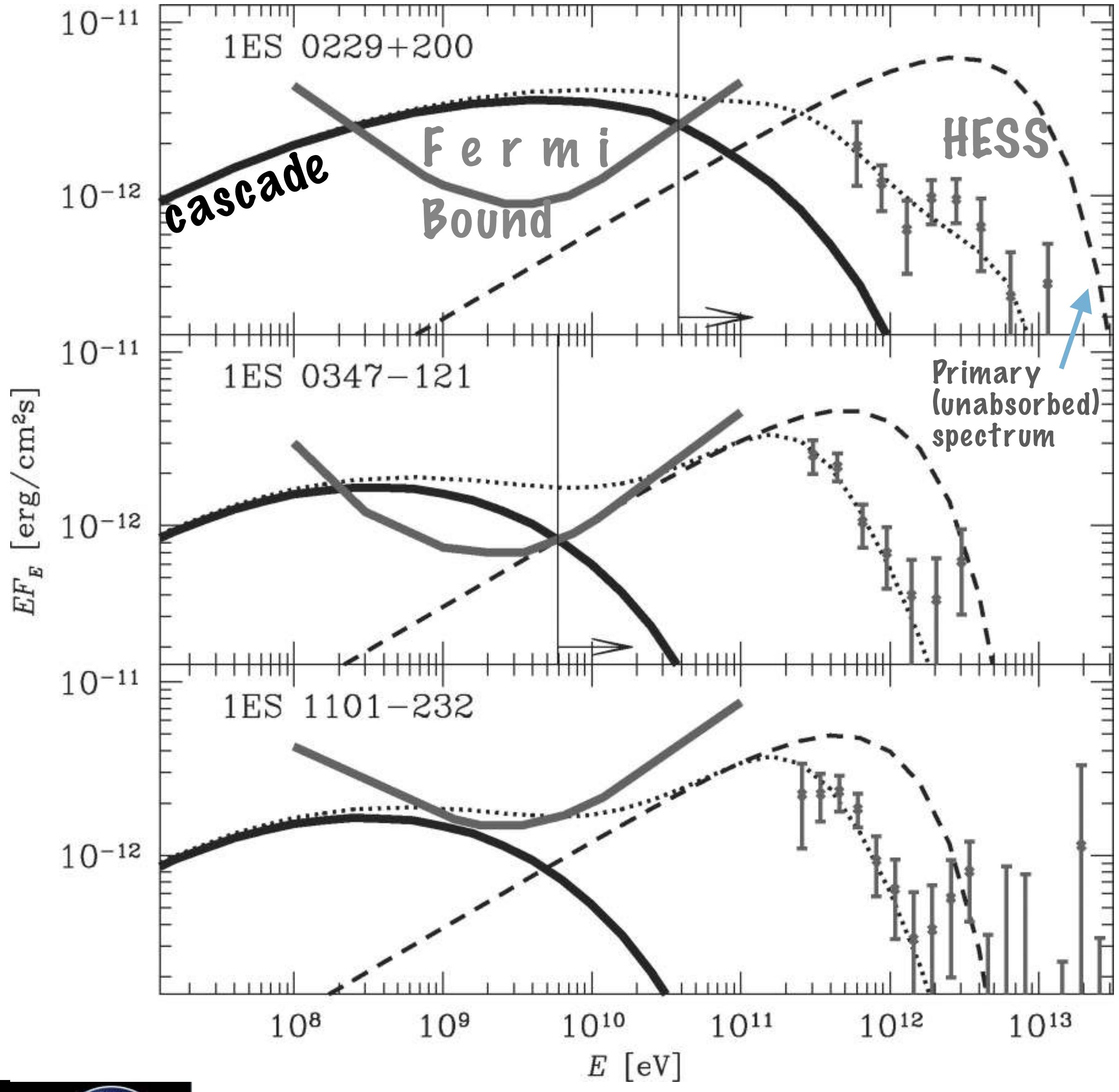

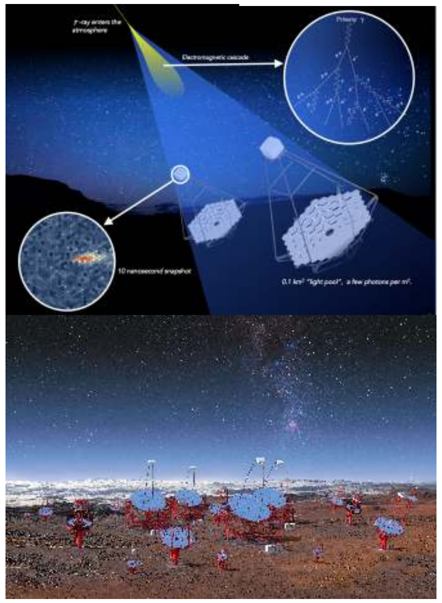

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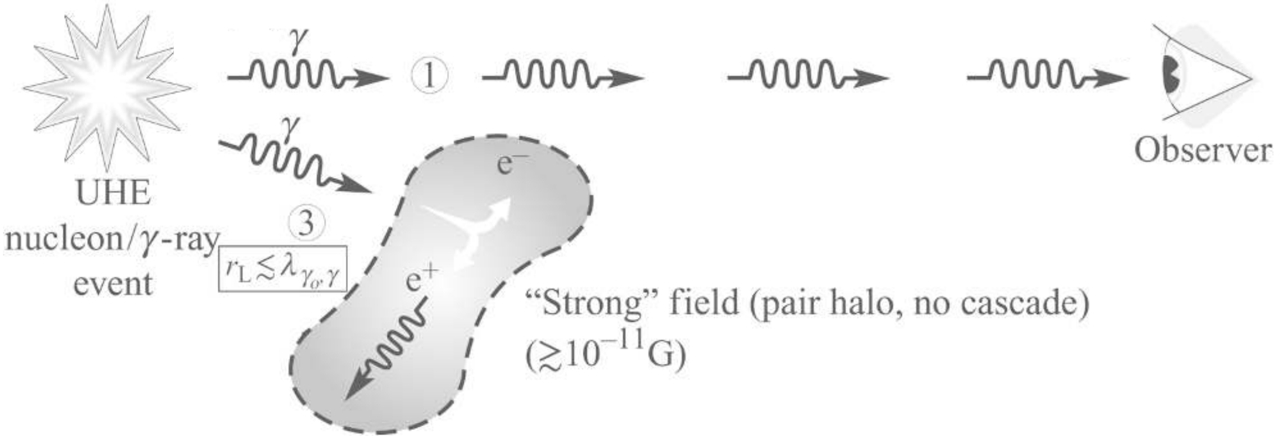

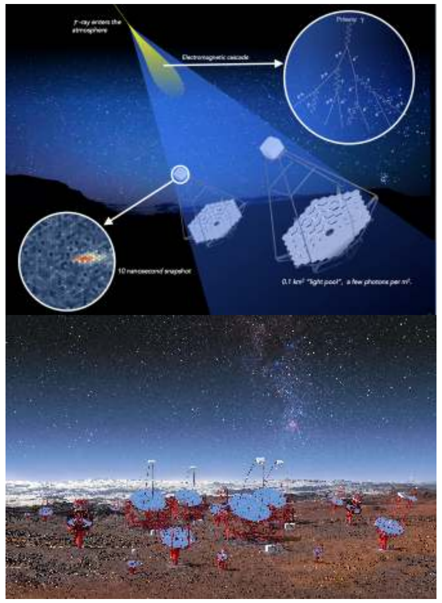

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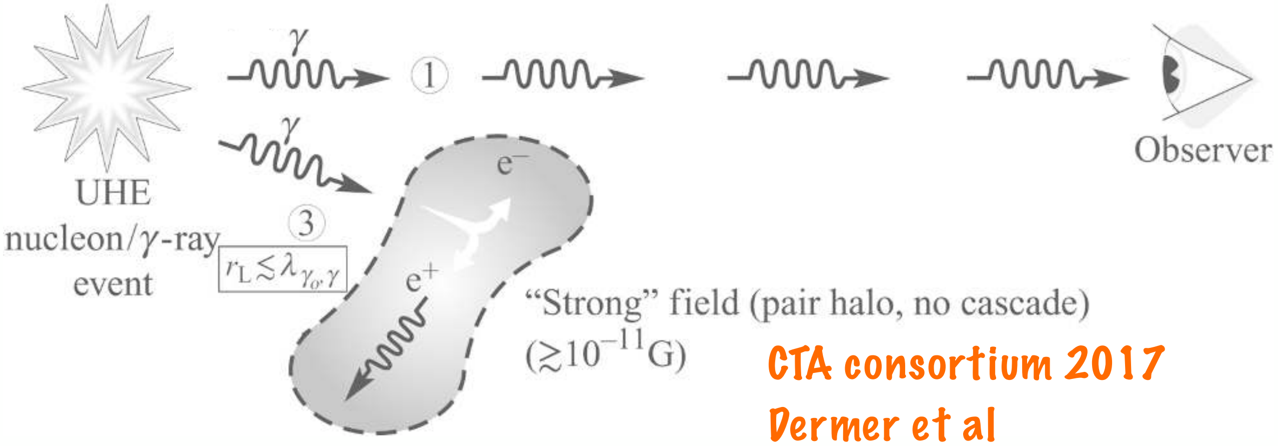
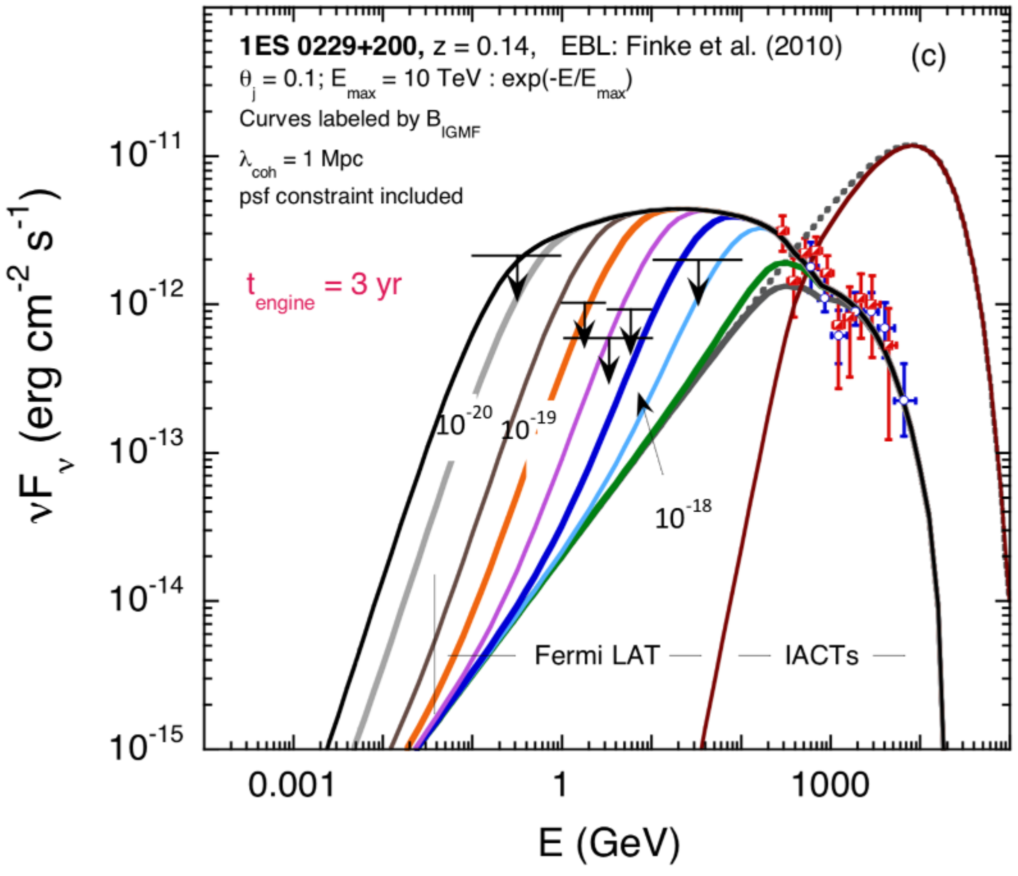
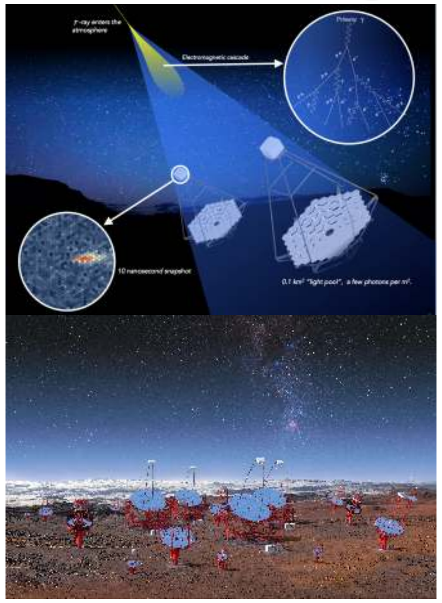
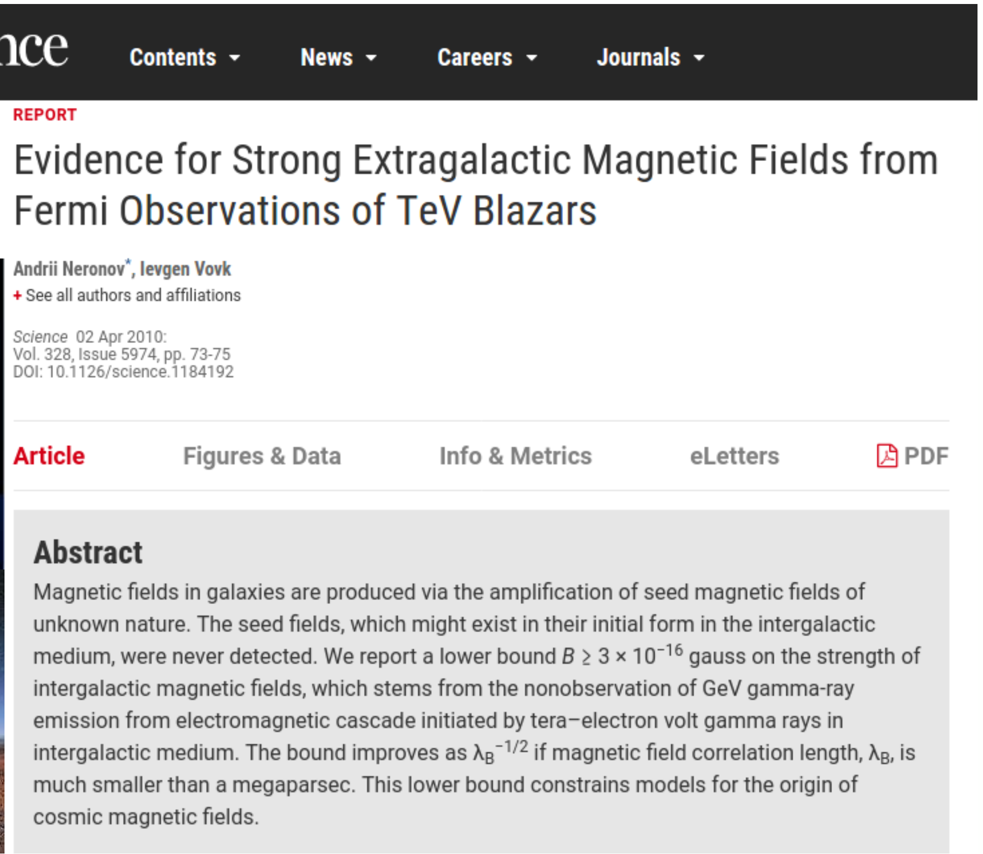


CTA consortium 2017
Dermer et al







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Article Figures & Data Info & Metrics eLetters PDF

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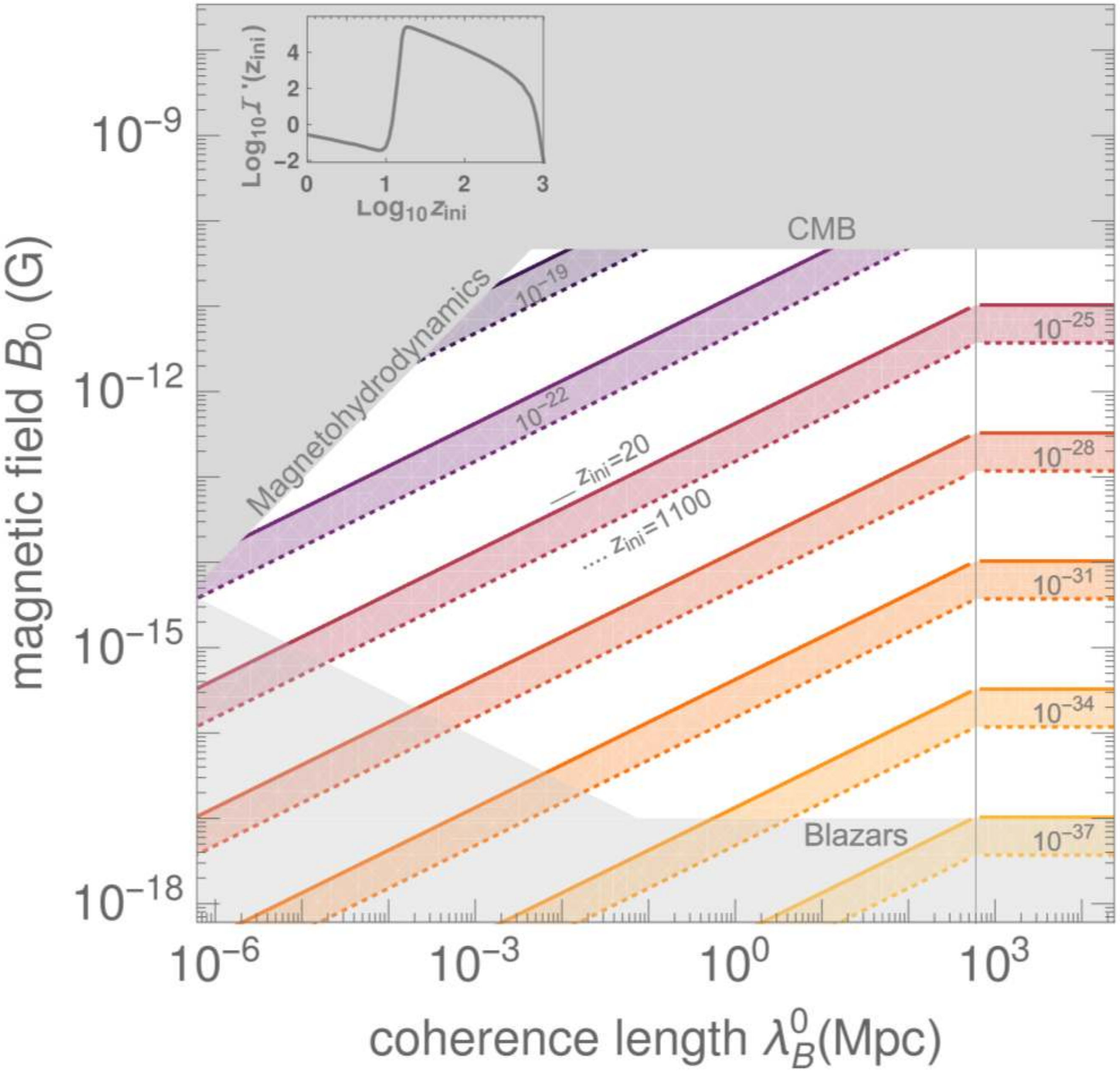
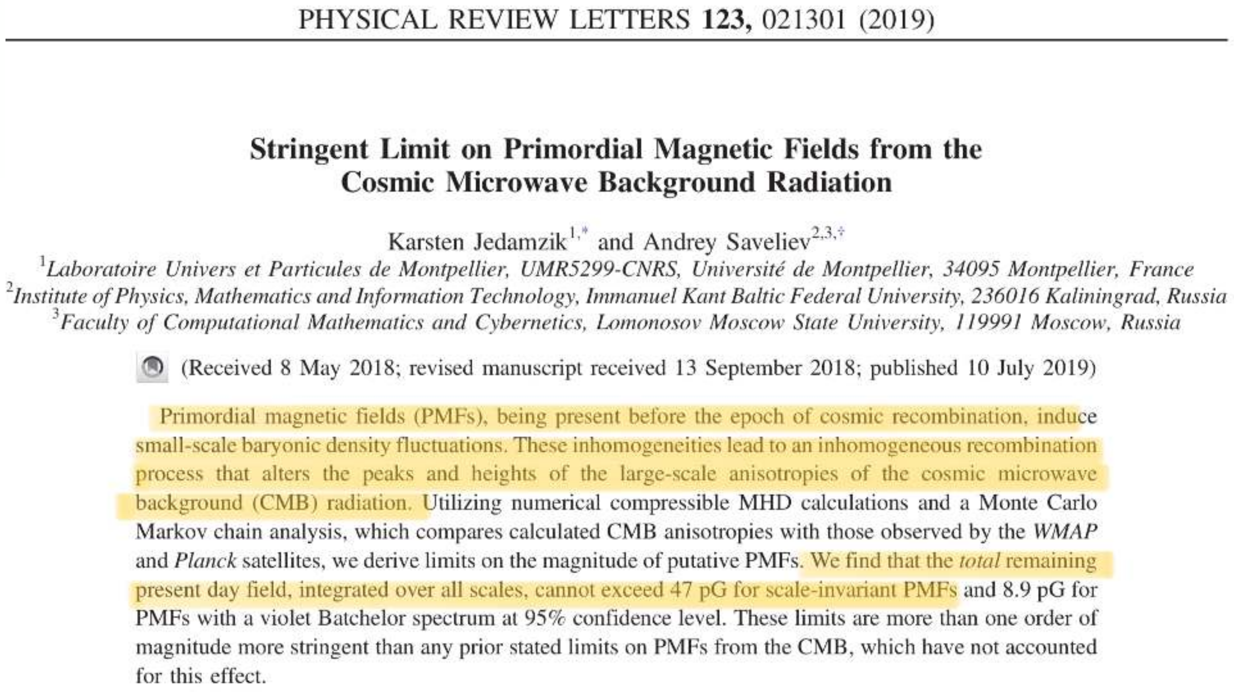


$$\mathcal{P} \equiv \int_{l.o.s.} \langle \Gamma_{g\leftrightarrow\gamma} \rangle \, dt$$



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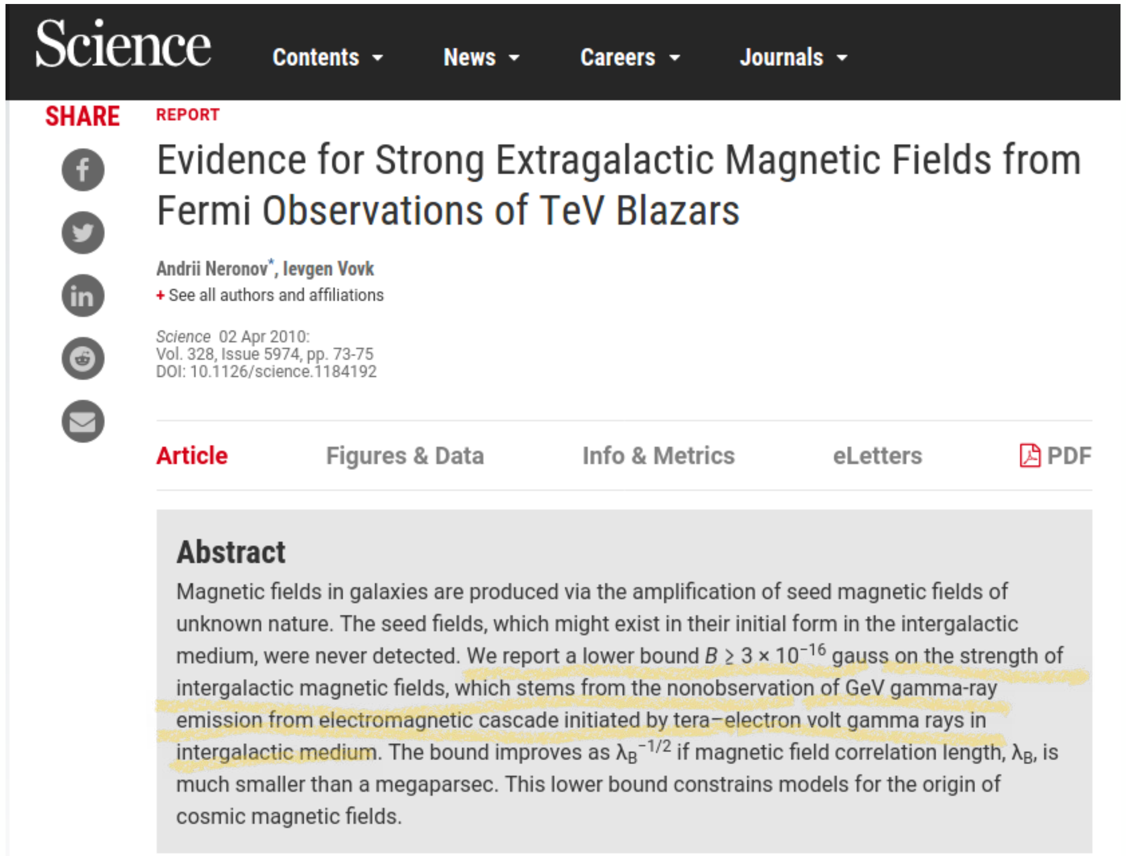

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DOI: 10.1126/science.1184192

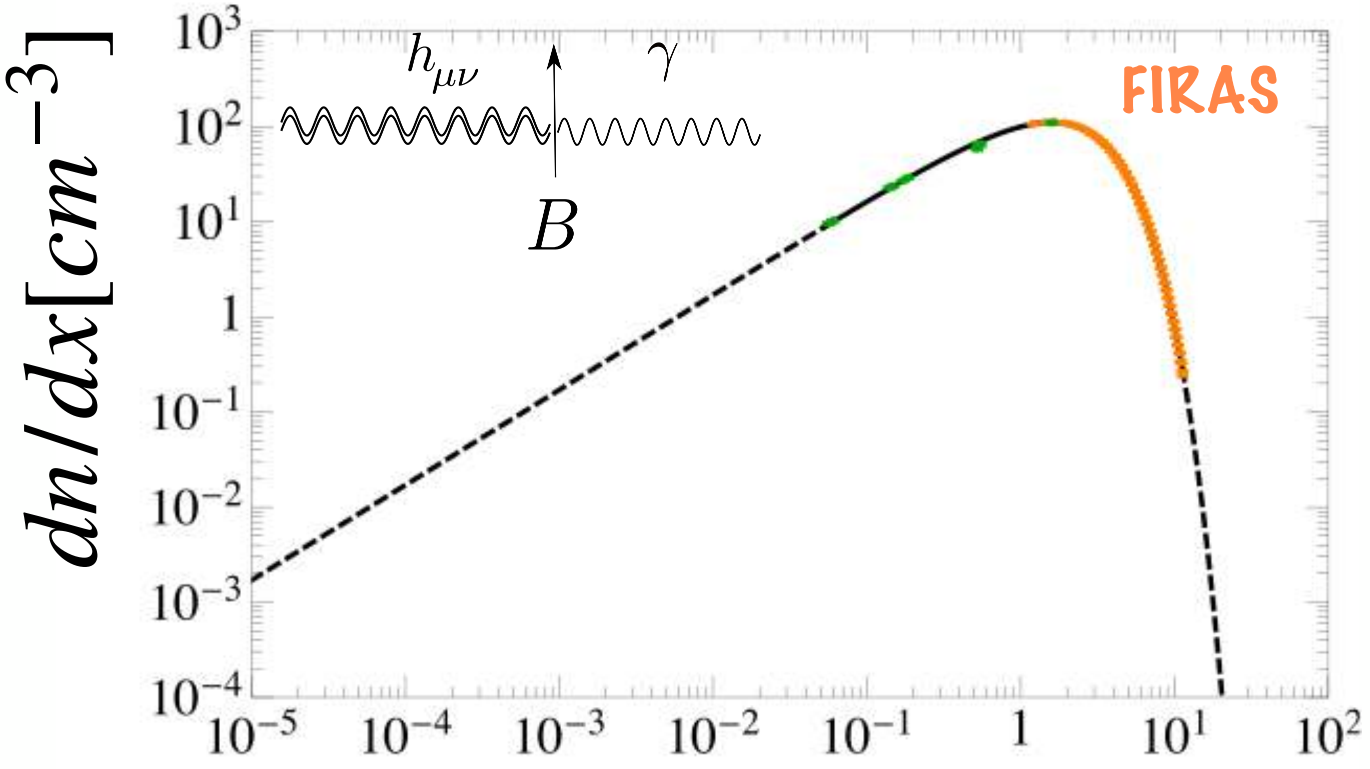
Abstract

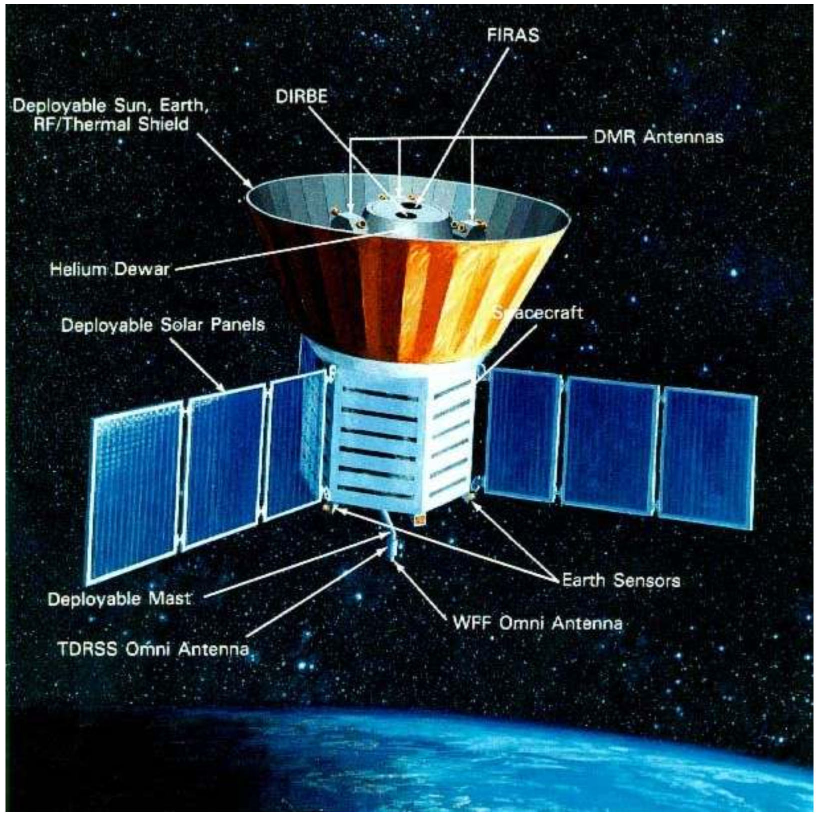
Magnetic fields in galaxies are produced via the amplification of seed magnetic fields of unknown nature. The seed fields, which might exist in their initial form in the intergalactic medium, were never detected. We report a lower bound $B \gtrsim 3 \times 10^{-16}$ gauss on the strength of intergalactic magnetic fields, which stems from the nonobservation of GeV gamma-ray emission from electromagnetic cascade initiated by tera–electron volt gamma rays in intergalactic medium. The bound improves as $\lambda_B^{-1/2}$ if magnetic field correlation length, λ_B, is much smaller than a megaparsec. This lower bound constrains models for the origin of cosmic magnetic fields.

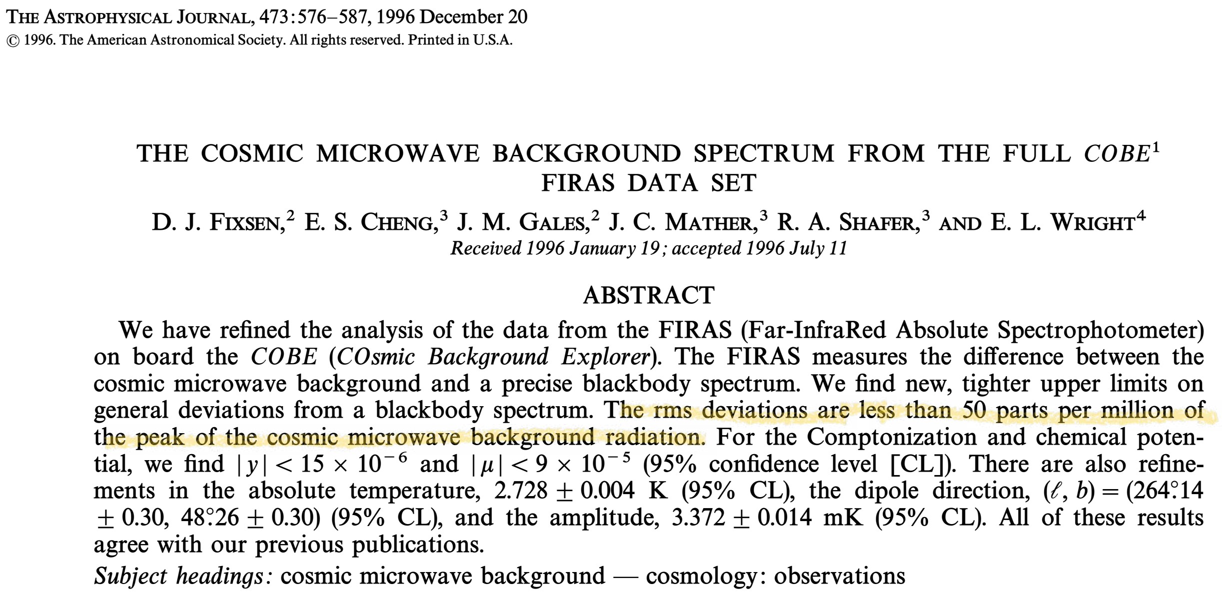
Camilo A. Garcia Cely

CMB observations and 21-cm cosmology

CMB distortions






THE ASTROPHYSICAL JOURNAL, 473:576–587, 1996 December 20

THE COSMIC MICROWAVE BACKGROUND SPECTRUM FROM THE FULL *COBE*[1] FIRAS DATA SET

D. J. FIXSEN,[2] E. S. CHENG,[3] J. M. GALES,[2] J. C. MATHER,[3] R. A. SHAFER,[3] AND E. L. WRIGHT[4]
Received 1996 January 19; accepted 1996 July 11

ABSTRACT

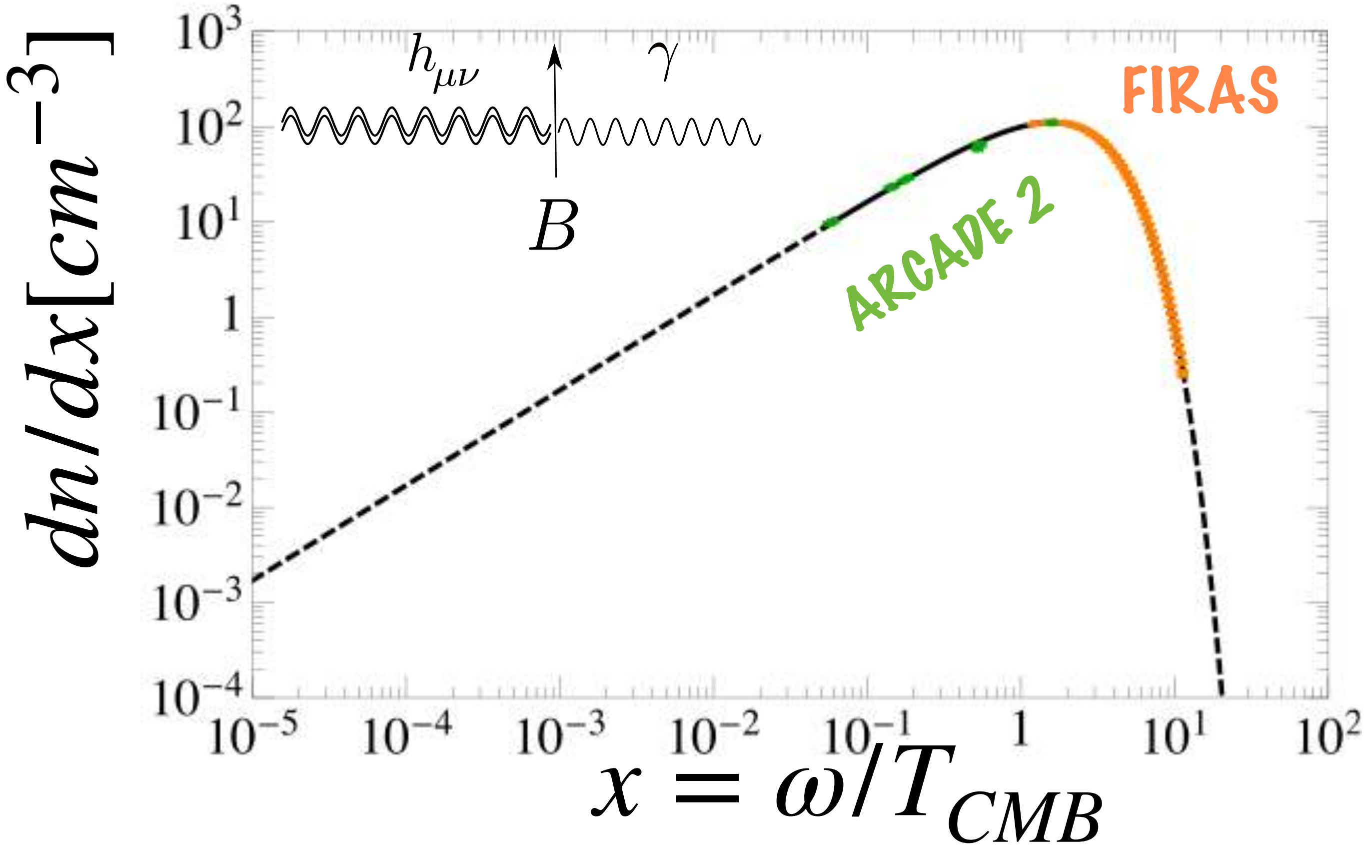
We have refined the analysis of the data from the FIRAS (Far-InfraRed Absolute Spectrophotometer) on board the *COBE* (*COsmic Background Explorer*). The FIRAS measures the difference between the cosmic microwave background and a precise blackbody spectrum. We find new, tighter upper limits on general deviations from a blackbody spectrum. The rms deviations are less than 50 parts per million of the peak of the cosmic microwave background radiation. For the Comptonization and chemical potential, we find $|y| < 15 \times 10^{-6}$ and $|\mu| < 9 \times 10^{-5}$ (95% confidence level [CL]). There are also refinements in the absolute temperature, 2.728 ± 0.004 K (95% CL), the dipole direction, $(\ell, b) = (264^\circ.14 \pm 0.30, 48^\circ.26 \pm 0.30)$ (95% CL), and the amplitude, 3.372 ± 0.014 mK (95% CL). All of these results agree with our previous publications.

Subject headings: cosmic microwave background — cosmology: observations

Competes with the cosmological constraints on radiation energy N_{eff}

Camilo A. Garcia Cely

Rayleigh-Jeans Tail



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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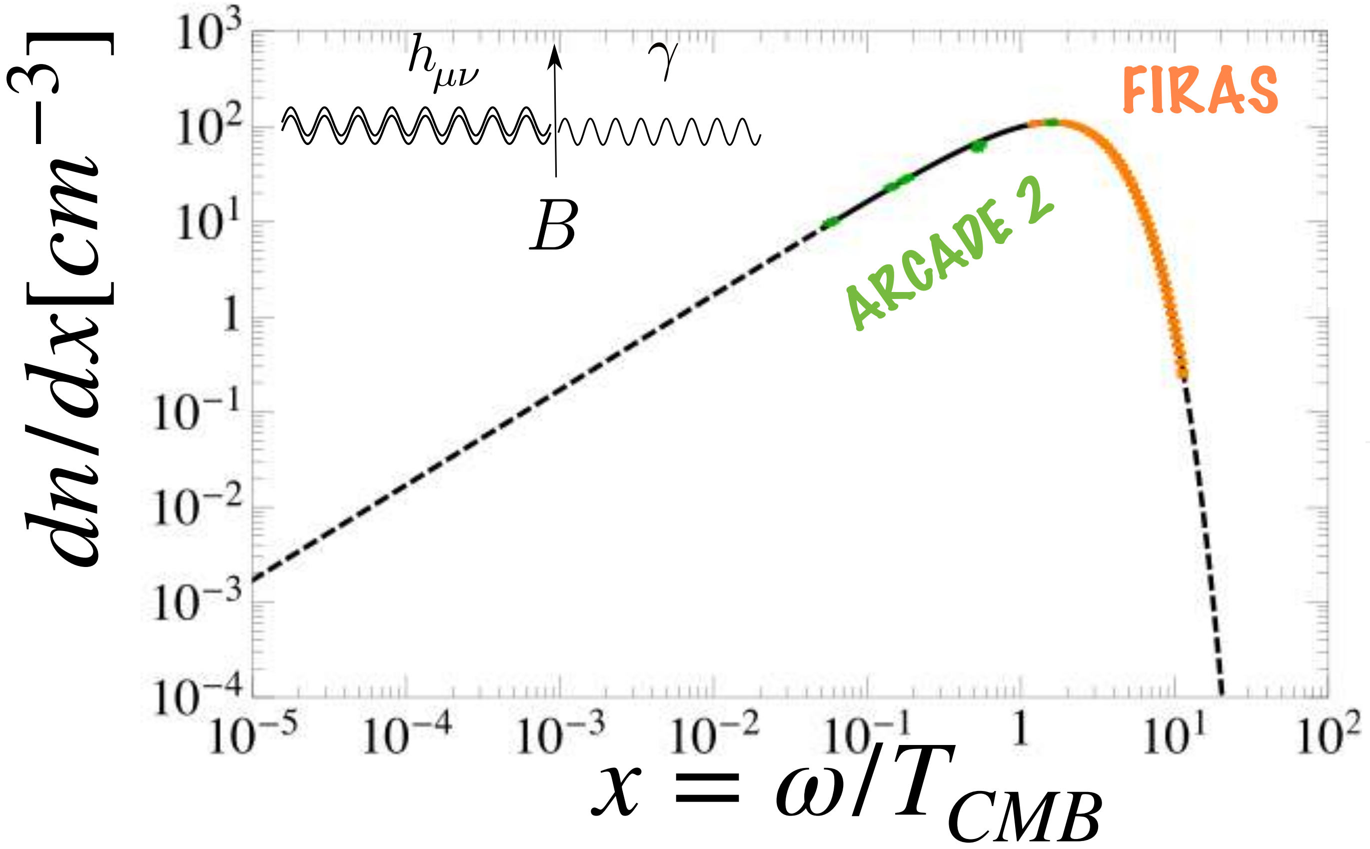
The Astrophysical Journal, Volume 734, Number 1

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

Rayleigh-Jeans Tail



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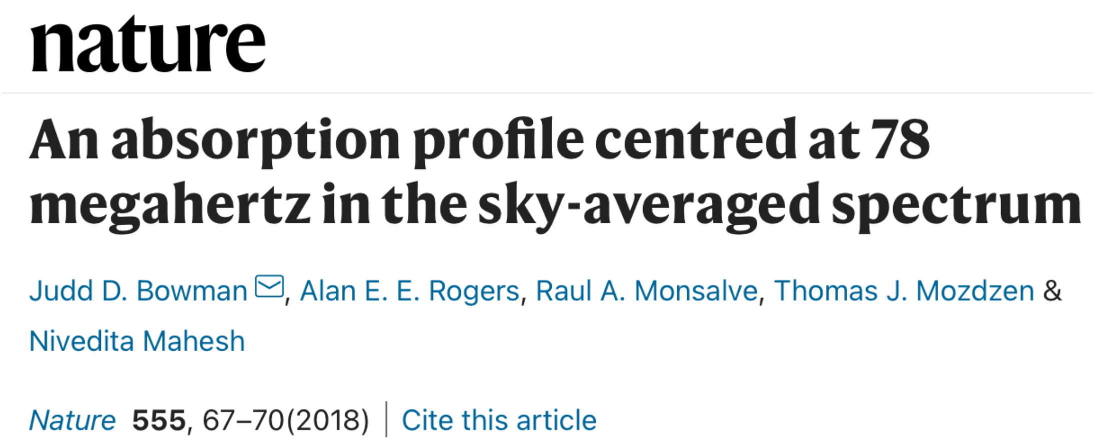


nature

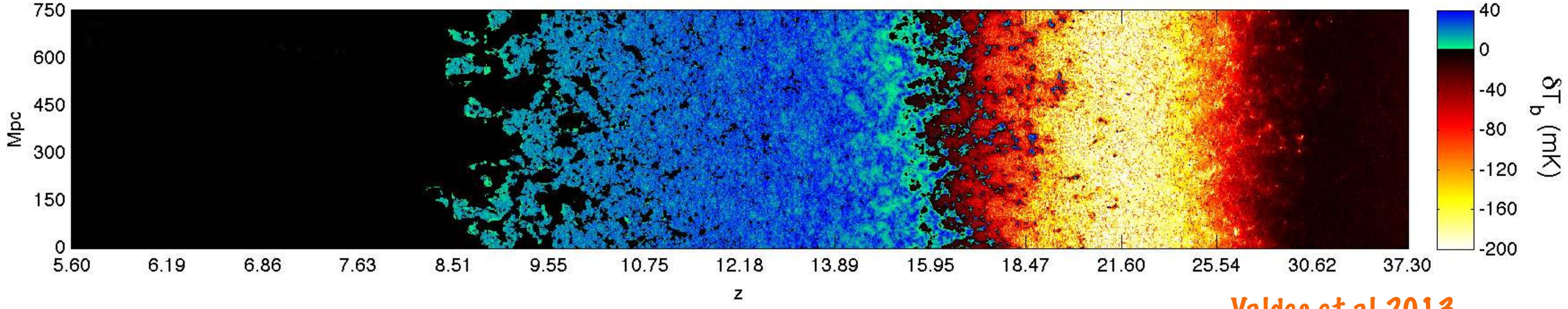
An absorption profile centred at 78 megahertz in the sky-averaged spectrum

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

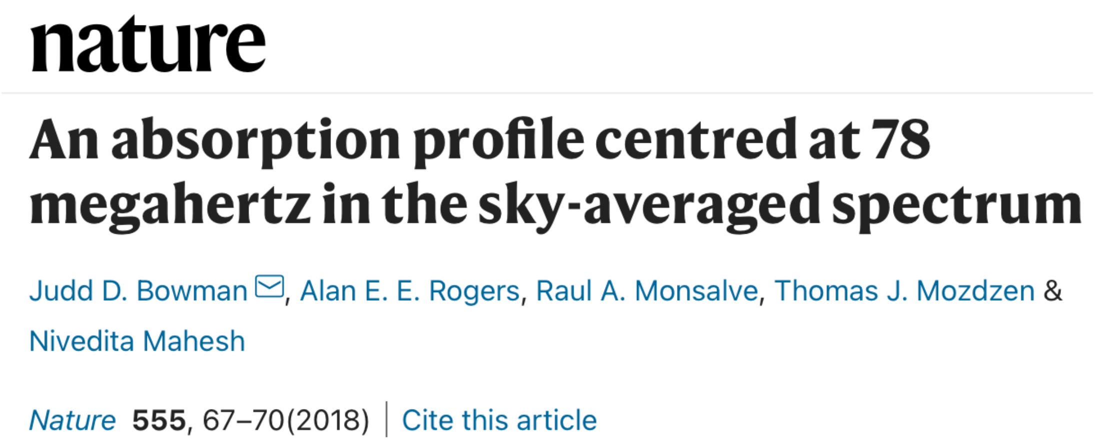
Nature **555**, 67–70(2018) | Cite this article

- Largely unexplored with upcoming advances in radio astronomy probing it in the near future.
- Puzzling signal by EDGES. (Experiment to Detect the Global Epoch of Reionization Signature)

Expectations for a 21 cm signal



Valdes et al 2013



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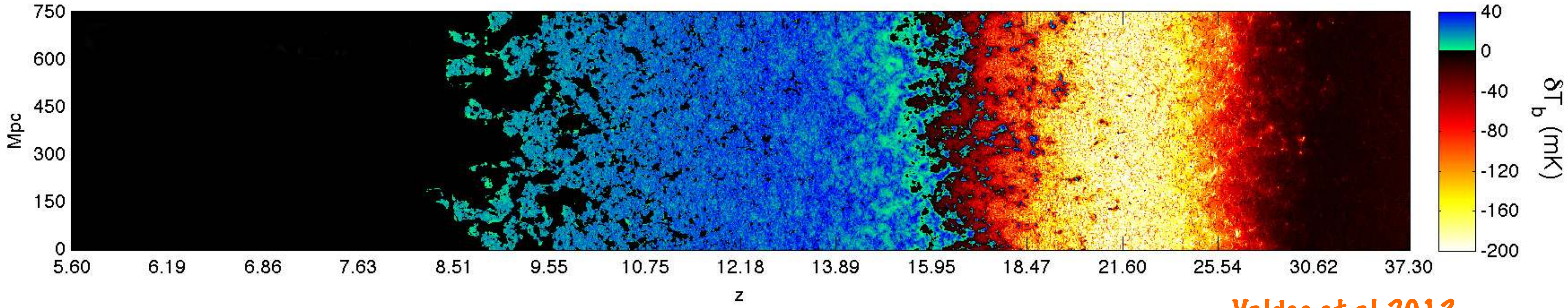


Valdes et al 2013

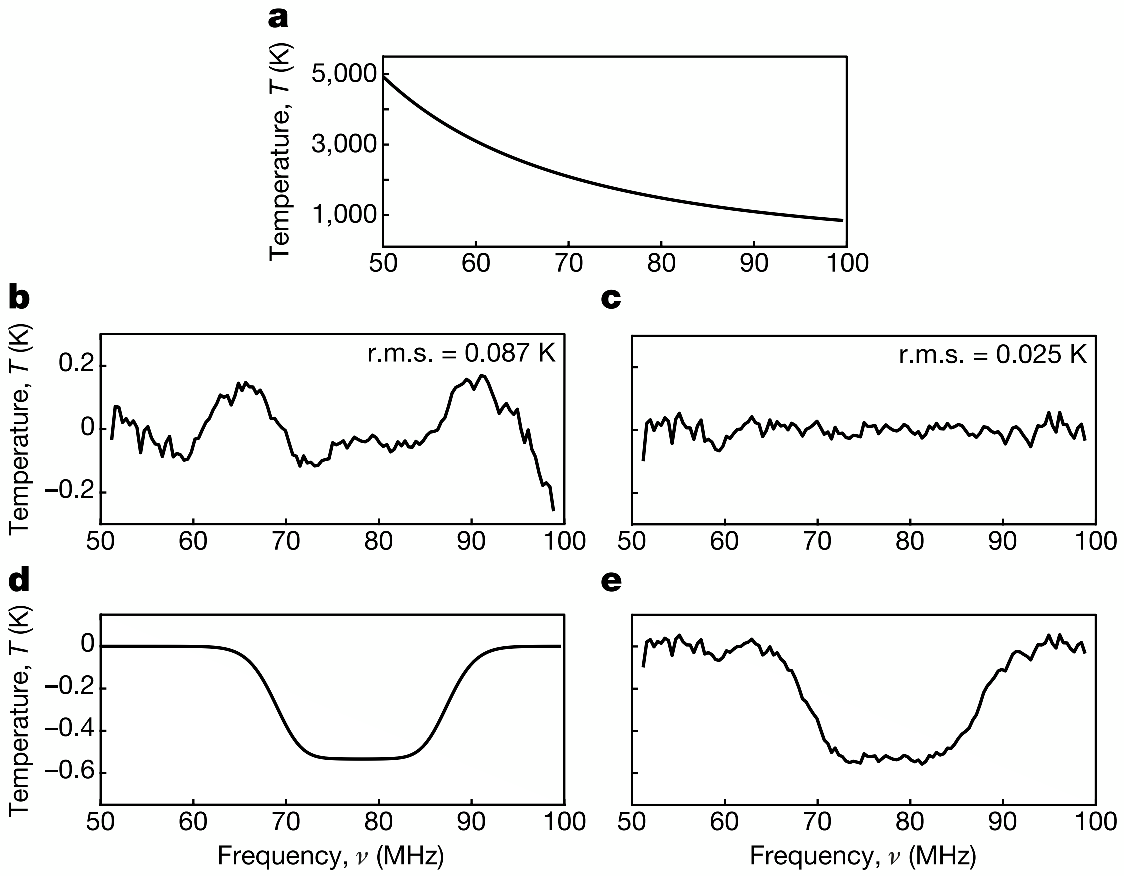
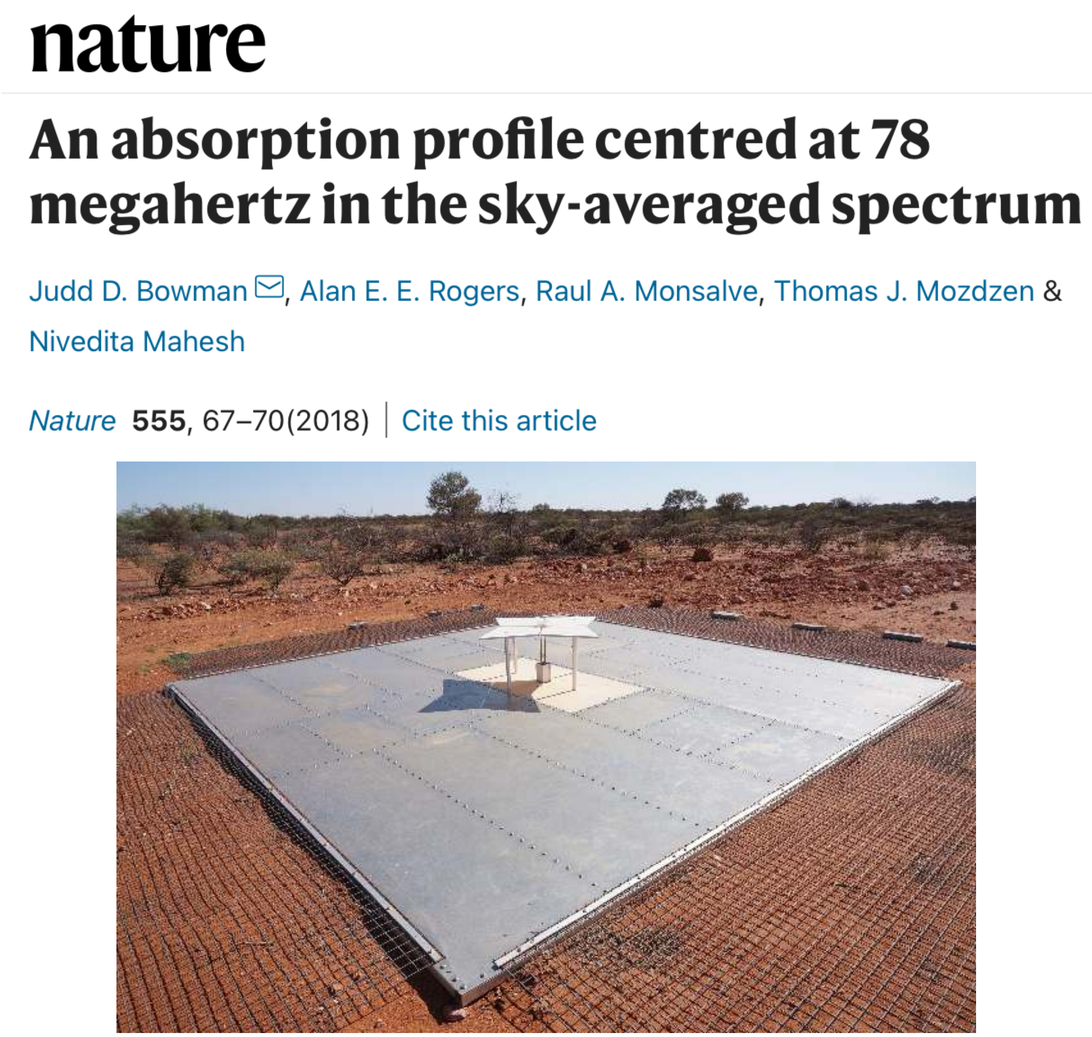


Figure 1 | Summary of detection. a, Measured spectrum for the reference dataset after filtering for data quality and radio-frequency interference. The spectrum is dominated by Galactic synchrotron emission. **b**, **c**, Residuals after fitting and removing only the foreground model (**b**) or the foreground and 21-cm models (**c**). **d**, Recovered model profile of the 21-cm absorption, with a signal-to-noise ratio of 37, amplitude of 0.53 K, centre frequency of 78.1 MHz and width of 18.7 MHz. **e**, Sum of the 21-cm model (**d**) and its residuals (**c**).



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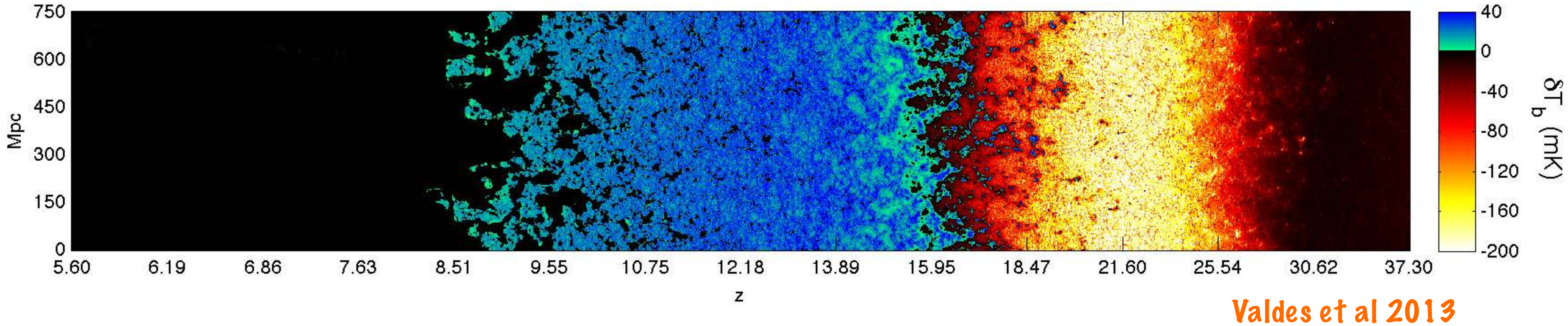
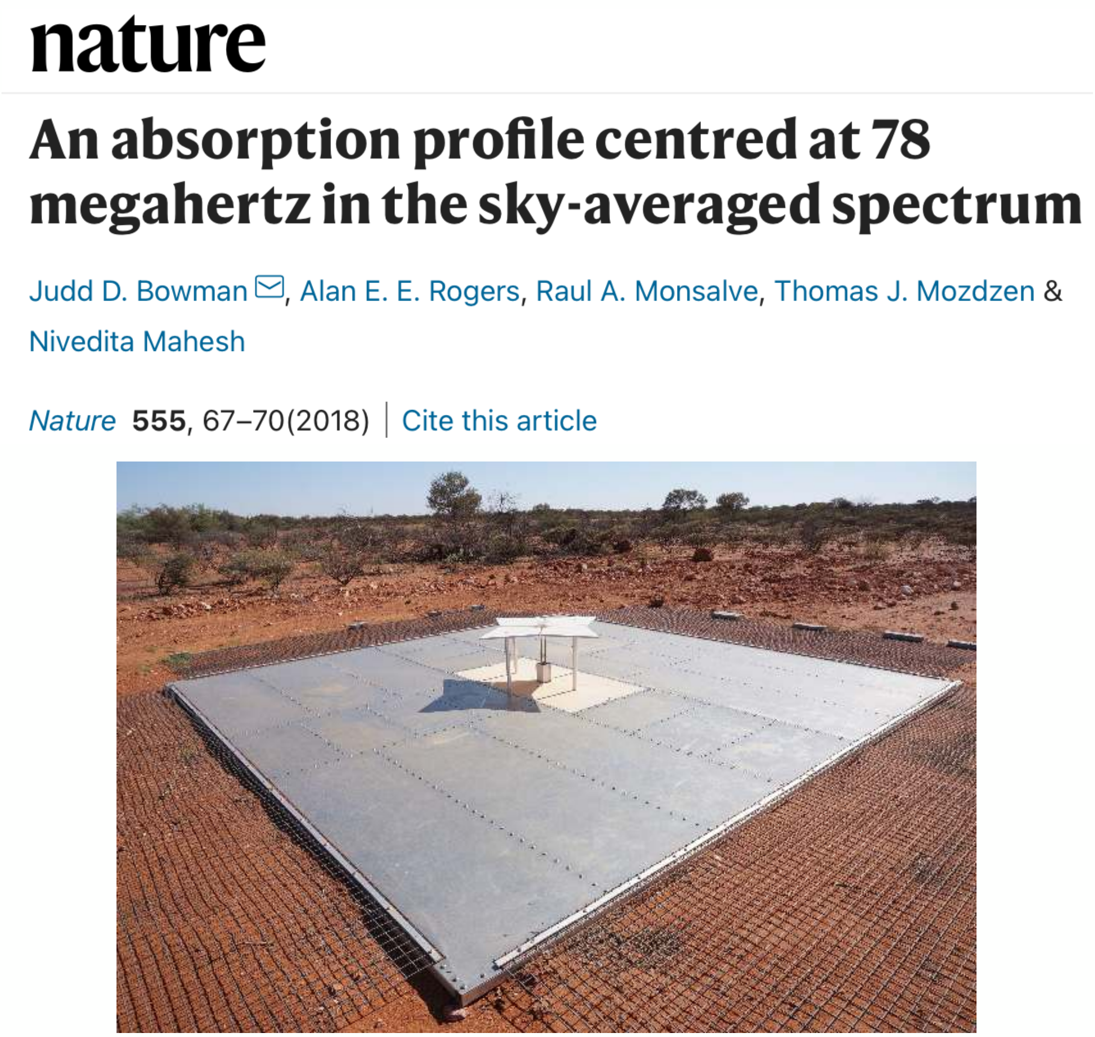


Valdes et al 2013

The absorption feature was found to be roughly twice as strong as previously expected. Conservatively, we may assume that the deviation from the expected value is due to foreground contamination, and place a bound on any stochastic GW background by using $\delta f_\gamma / f_\gamma \lesssim 1$ at 78 MHz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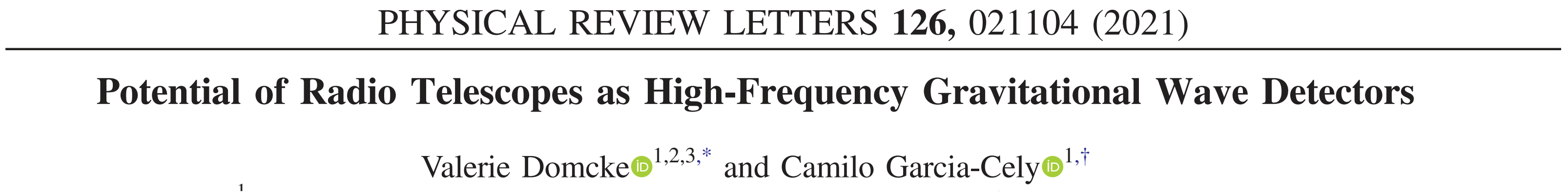
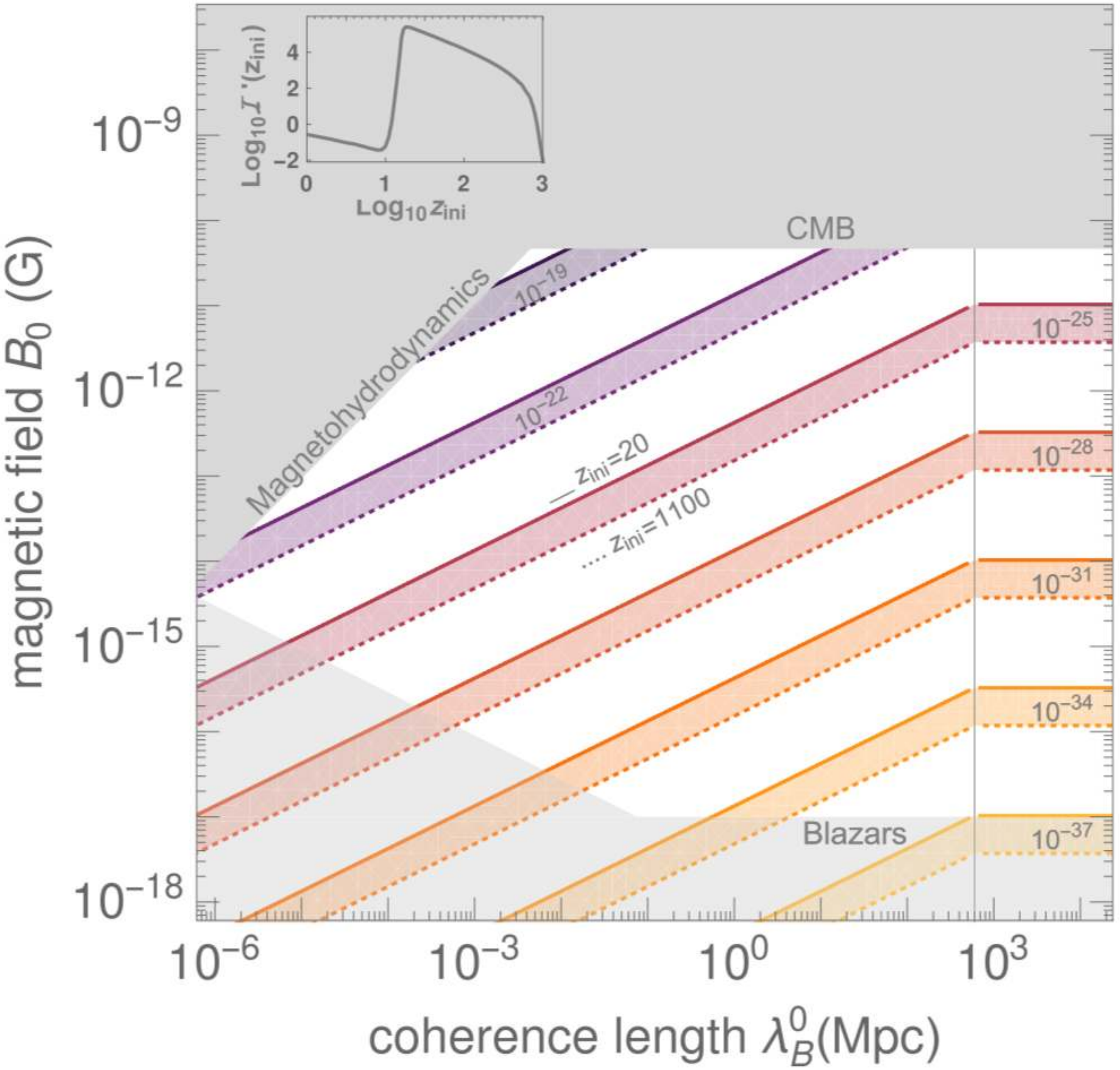
Upper bounds on stochastic gravitational waves

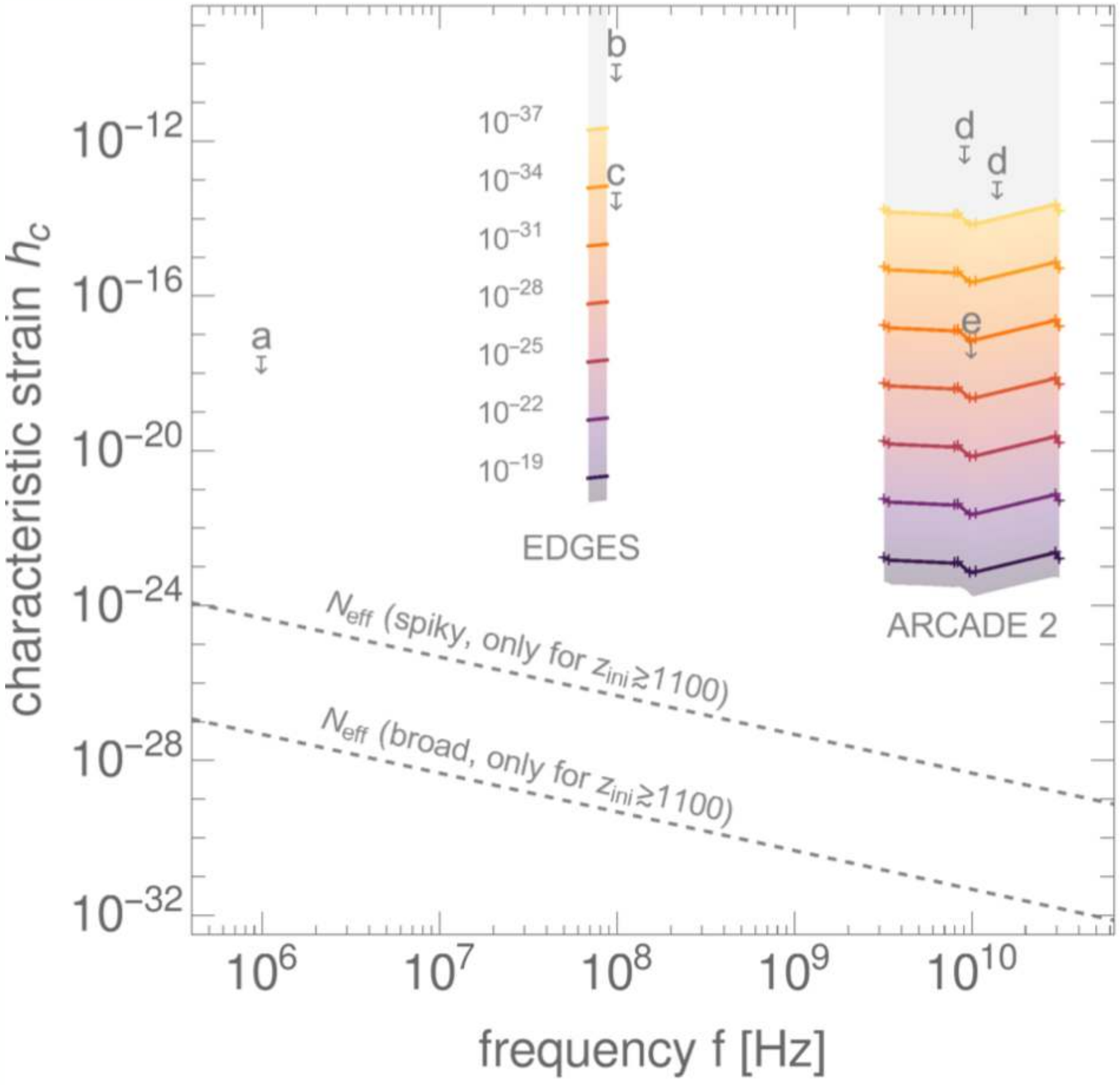


PHYSICAL REVIEW LETTERS **126,** 021104 (2021)

Potential of Radio Telescopes as High-Frequency Gravitational Wave Detectors

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





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

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

Conclusions

- The Gertsenshtein effect during the dark ages provides a powerful way to probe gravitational waves 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 gravitational waves.

- This highlights the interesting prospects associated with multi-messenger astronomy.