EXPERIMENTAL UPPER LIMITS ON (ULTRA) HIGH-FREQUENCY GRAVITATIONAL WAVES AND PROSPECTS FOR MORE: MAGNETIC CONVERSION DETECTORS AND CORRELATED INTERFEROMETRY

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ICTP workshop, Trieste

14/10/2019

Work in collaboration with: Aldo Ejlli, Mike Cruise, Damian Ejlli, and Giampaolo Pisano

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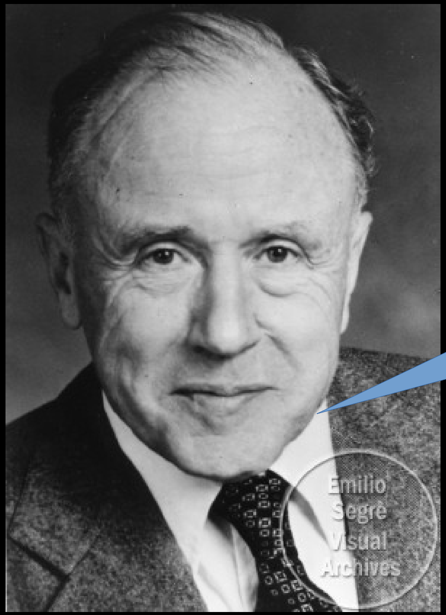
Joseph Weber: Pioneer of GW detection

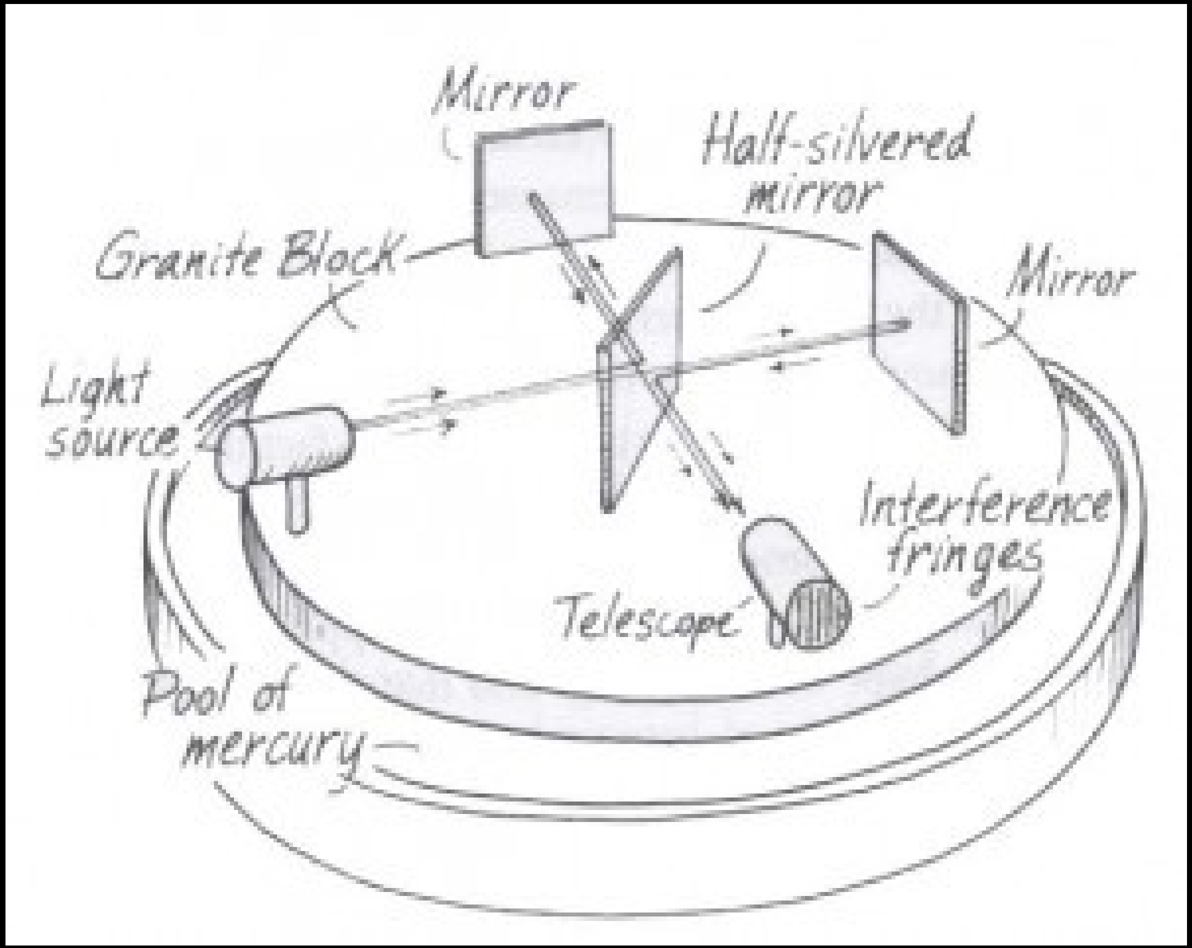
1969: Sensitivity ~10 million times less that IFO’s today.

John A. Wheeler

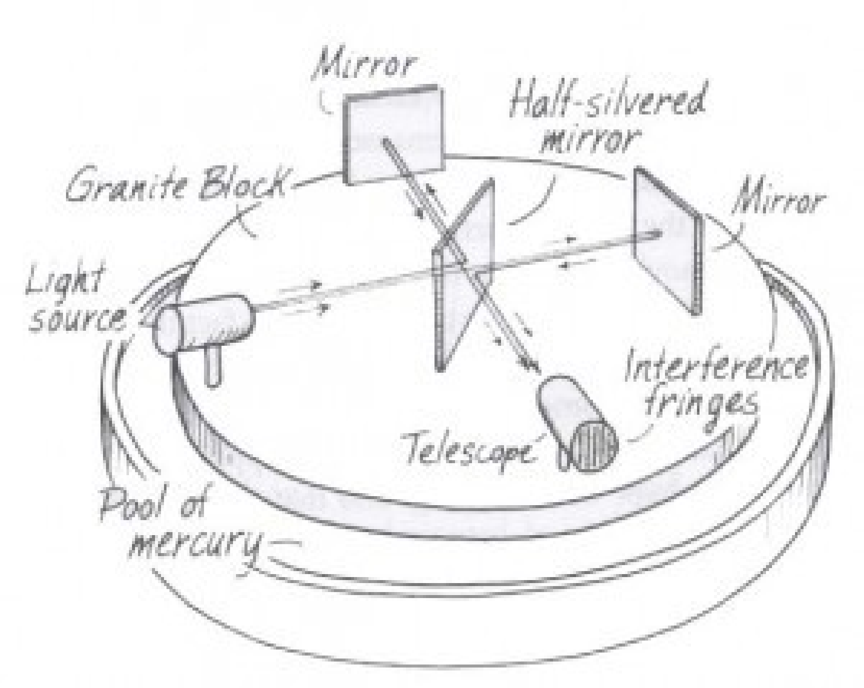
He [Weber] threw himself with religious fervor at the gravitational waves and pursued them for the rest of his career. Sometimes I wonder if I didn’t fill him with too much enthusiasm for this monumental task.

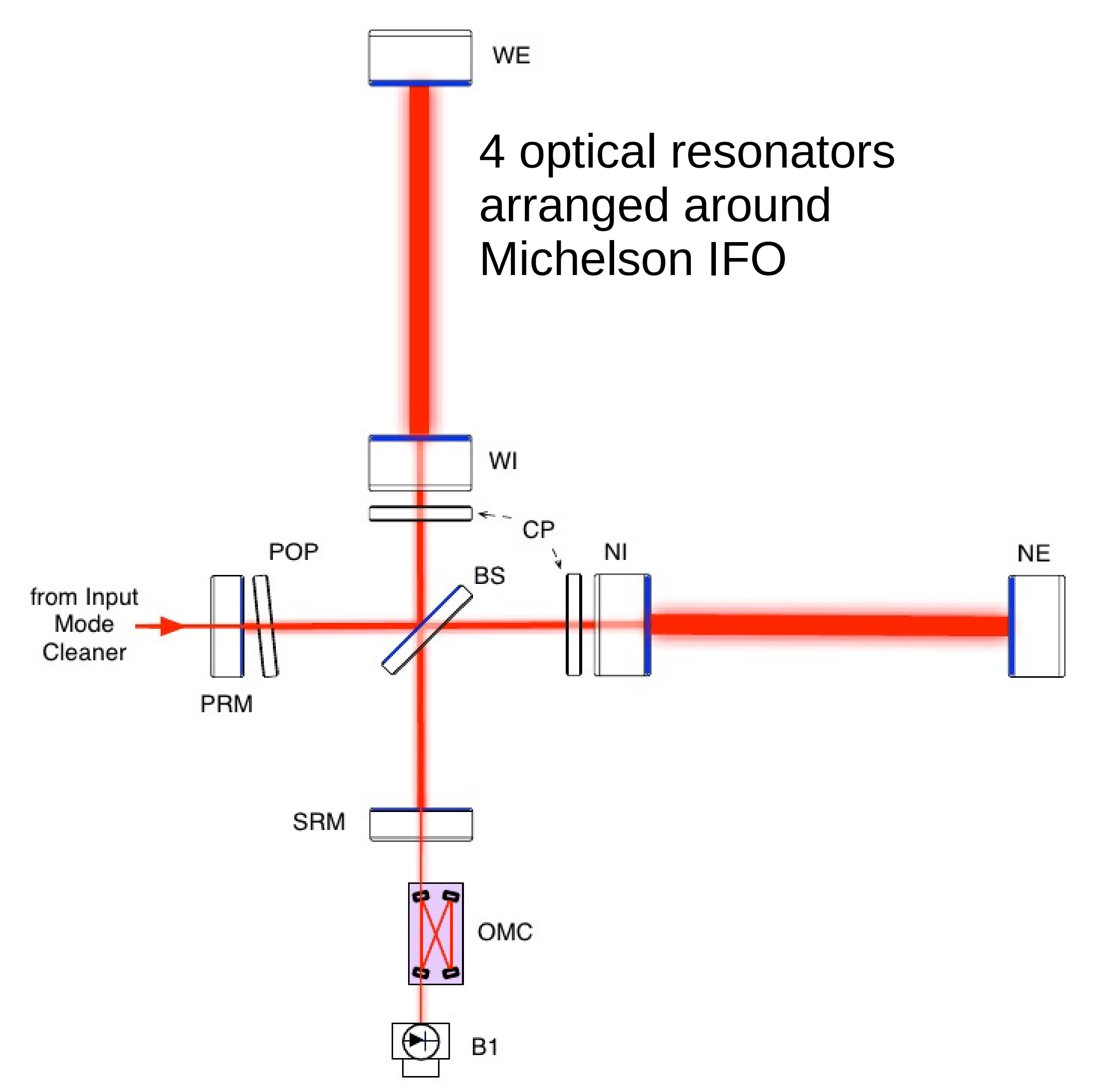


Michelson Interferometer



Michelson, with additions...



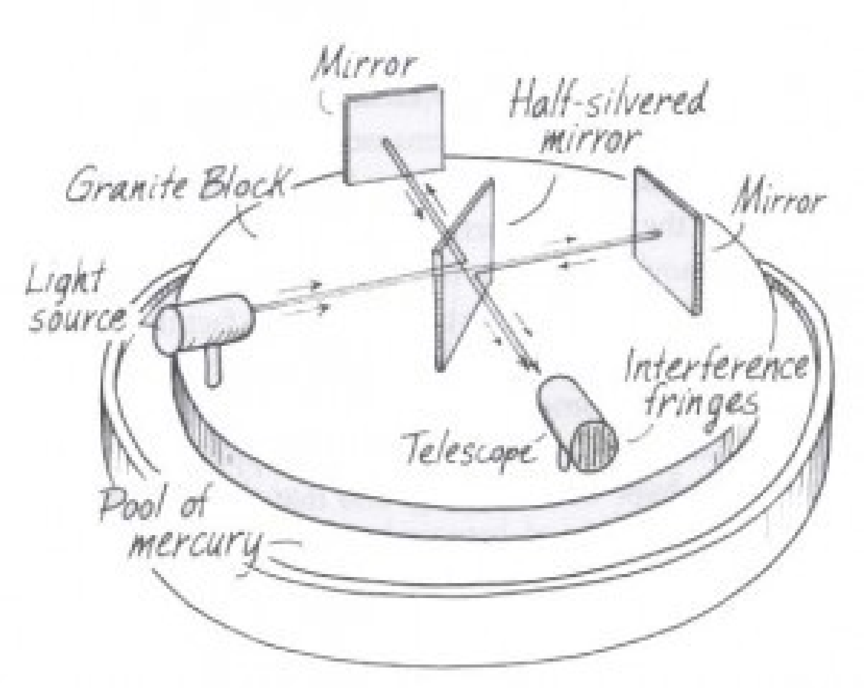


Michelson-Morley experiment:
Accuracy: 10^-8 m (10^-9 relative)

10m arm-length

Advanced Interferometer: 3-4 km arm-length
Accuracy: 10^-19 m (3 x 10^-23 relative), 100Hz BW

Michelson, with additions...



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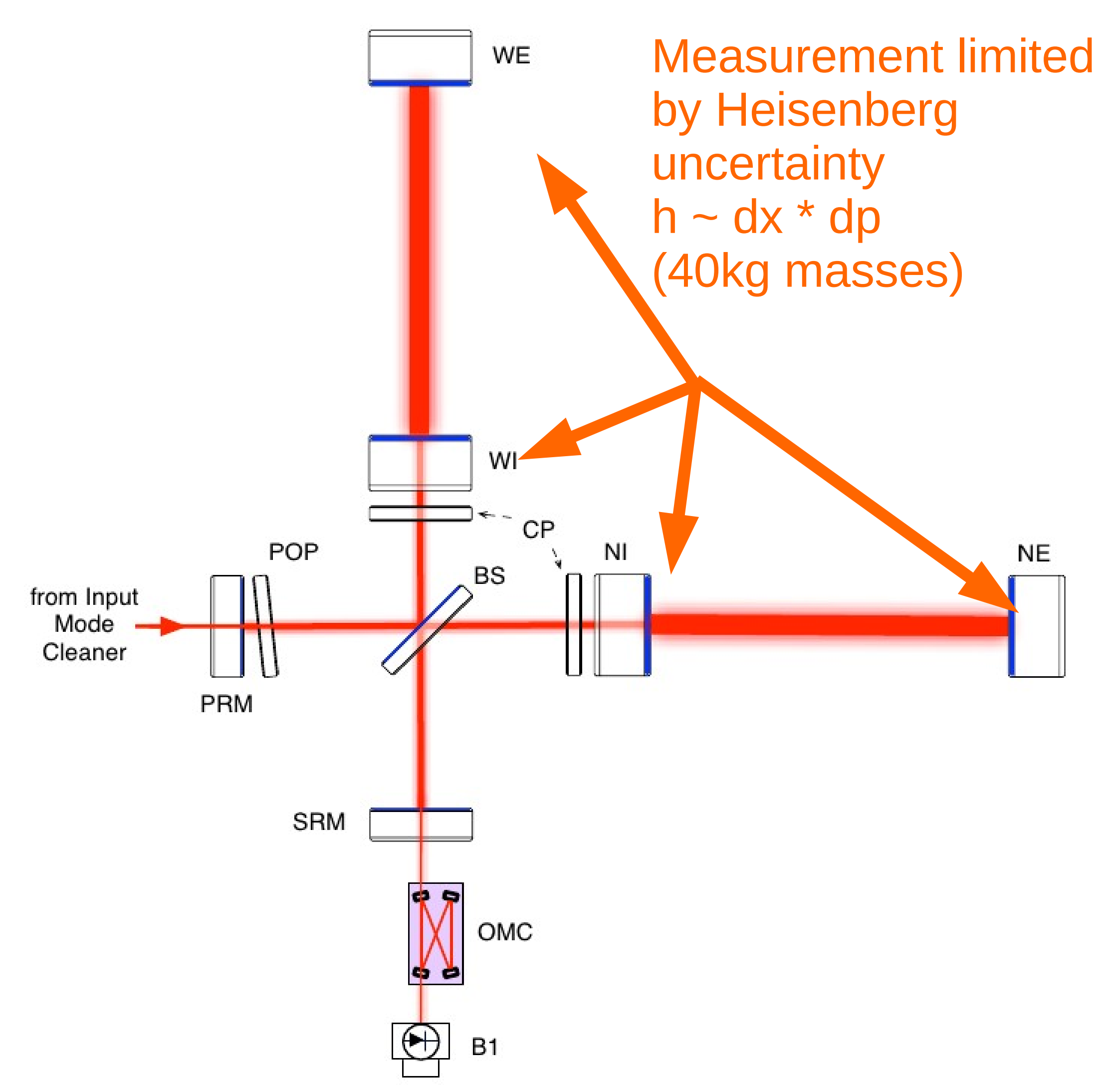

Advanced Interferometer: 3-4 km arm-length
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Other Interferometers

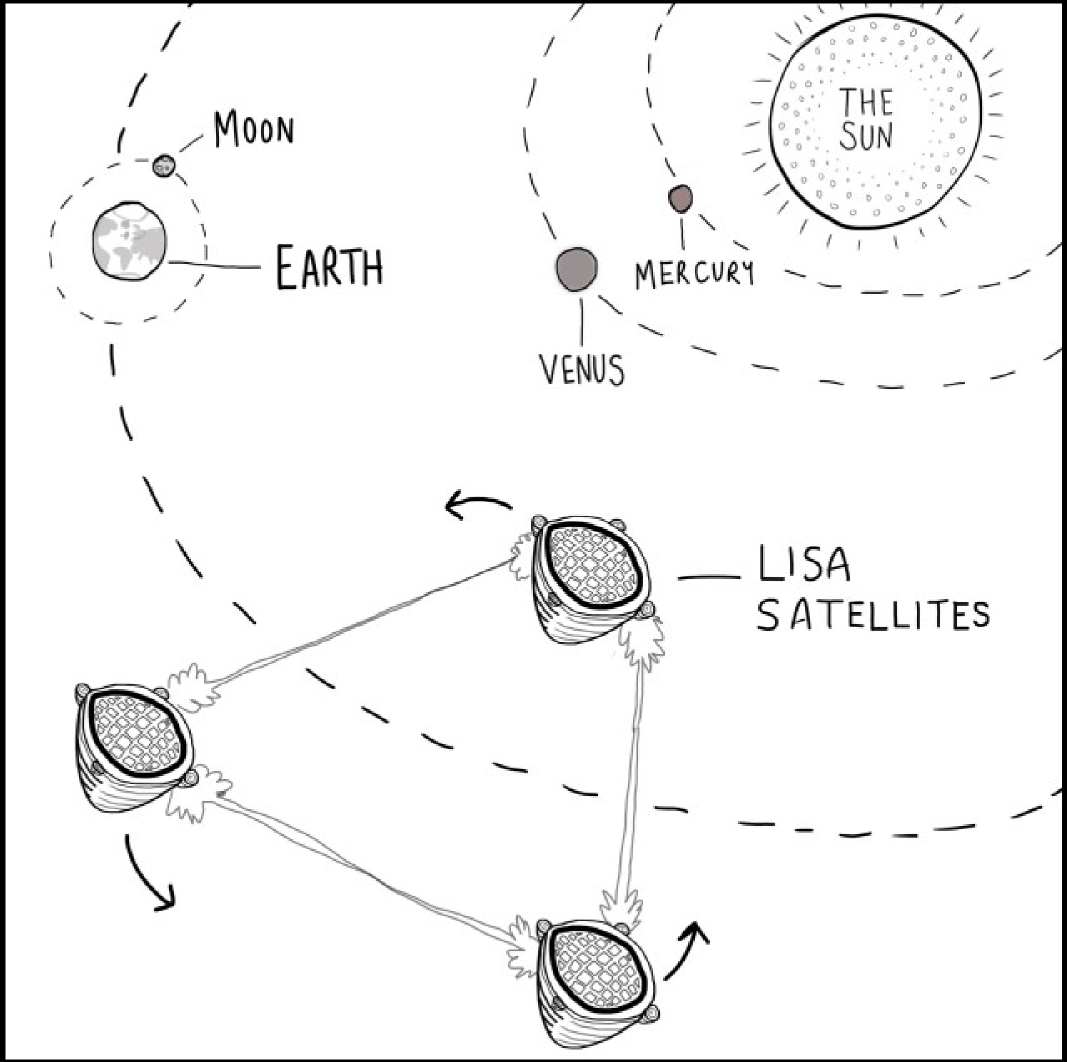
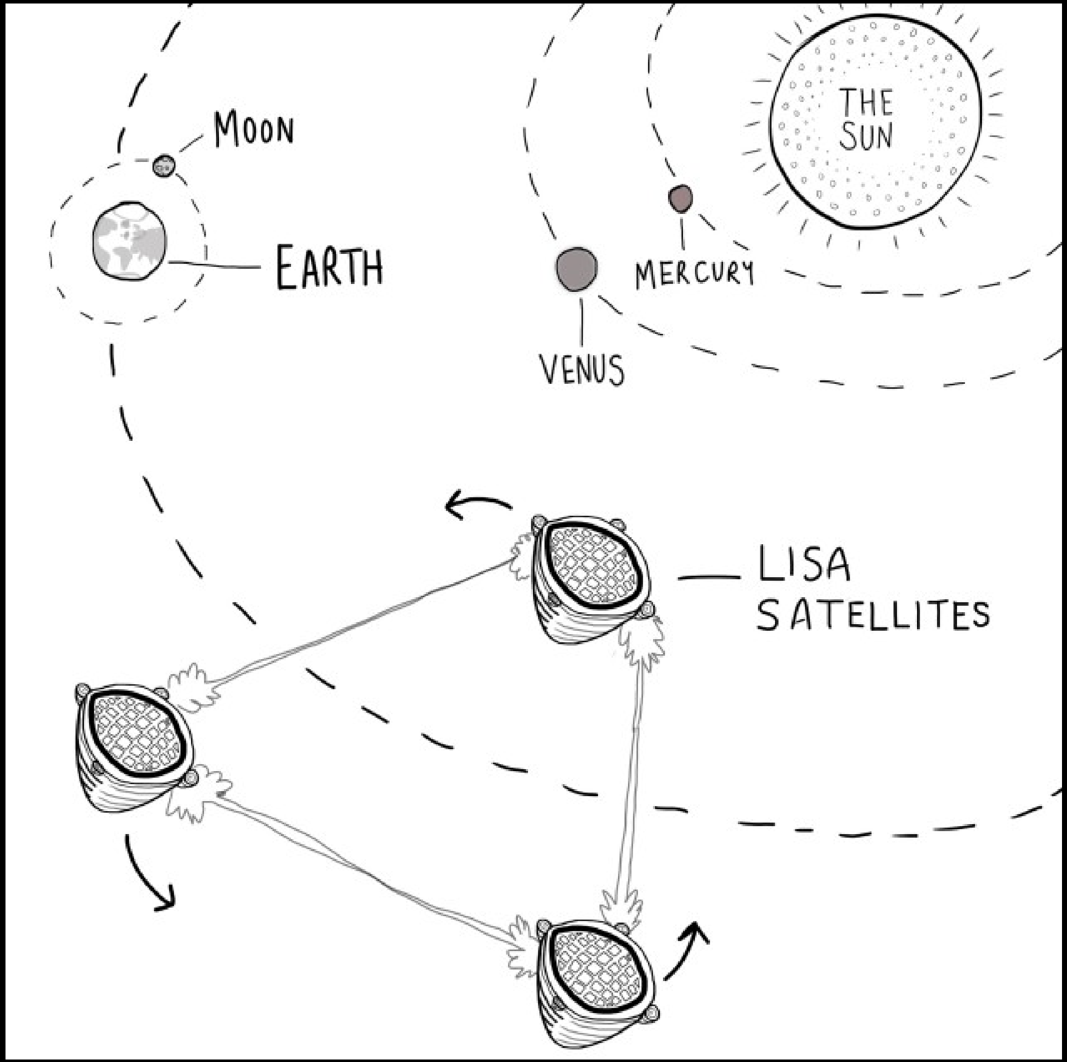


Illustration: Josh Field

Other Interferometers



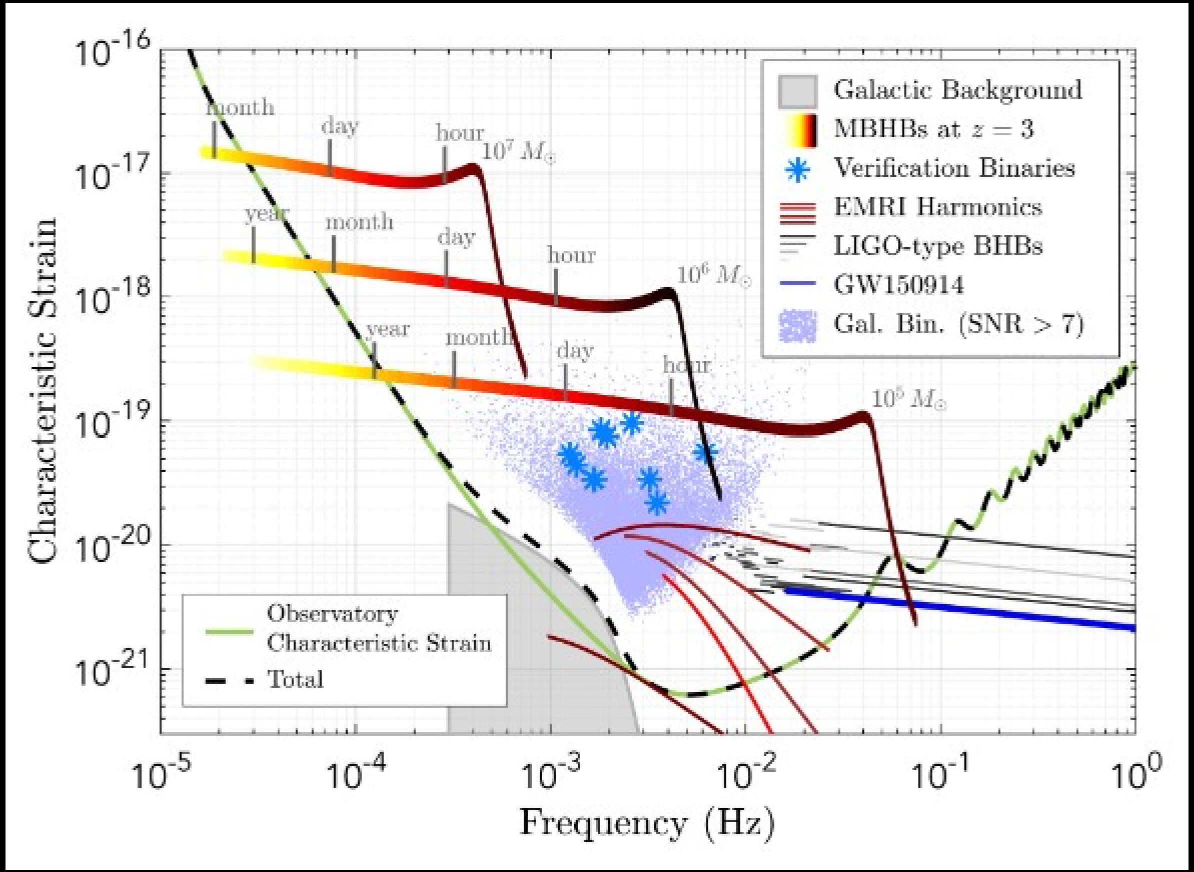
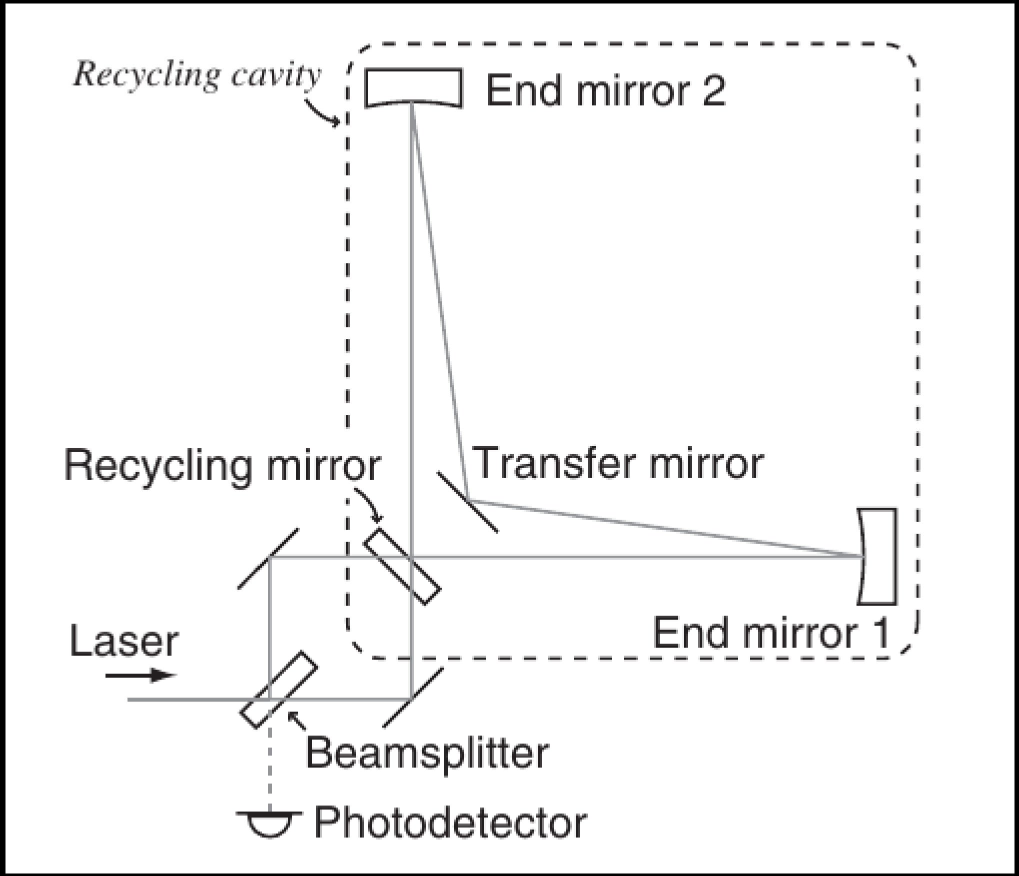
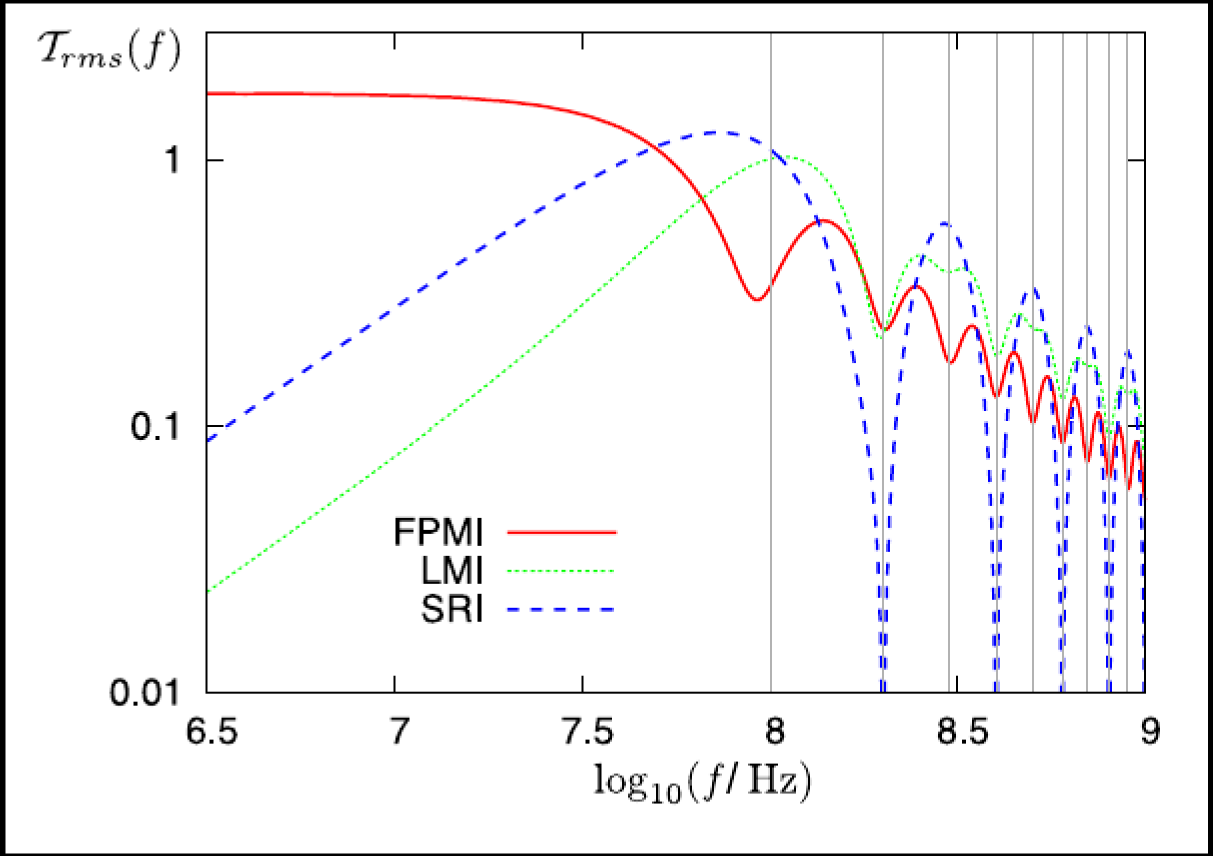


Illustration: Josh Field

Japanese synchronous recycling interferometer (100 MHz)





Fermilab ‘holometer’ interferometer
(1-13 MHz)

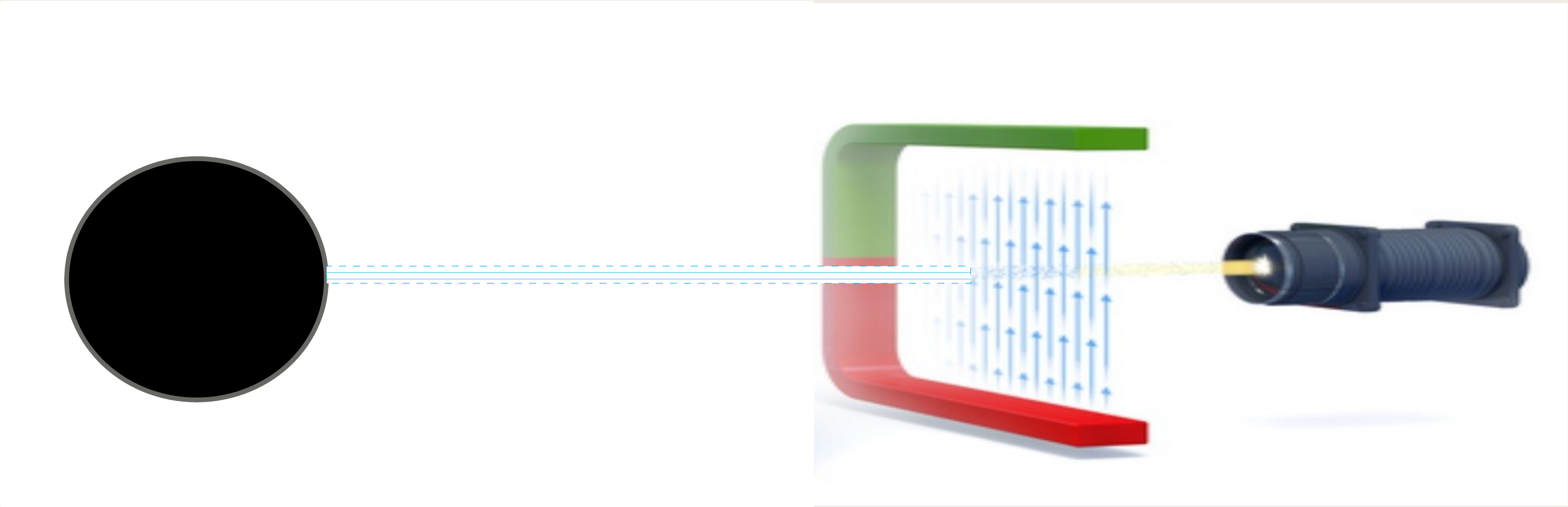
Interferometry gets harder at high frequencies

- h = dL / L → loss of strain (h) due to smaller L
- Small L → small beam sizes → harder to operate high power to reduce shot noise

The (inverse) Gertsenshtein effect

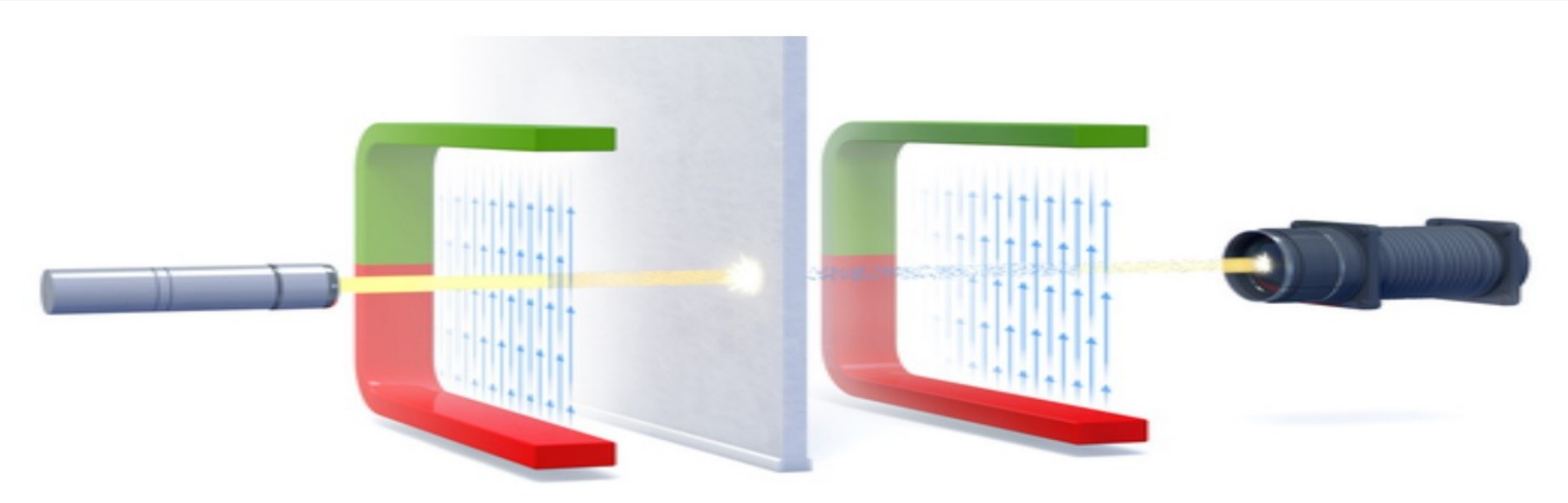
- Gravitational-waves propagating in magnetic fields convert into photons.

  (G. A. Lupanov JETP 25, 76 (1967), Gertsenshtein, Sov. Phys., JETP 14, 84 (1962))



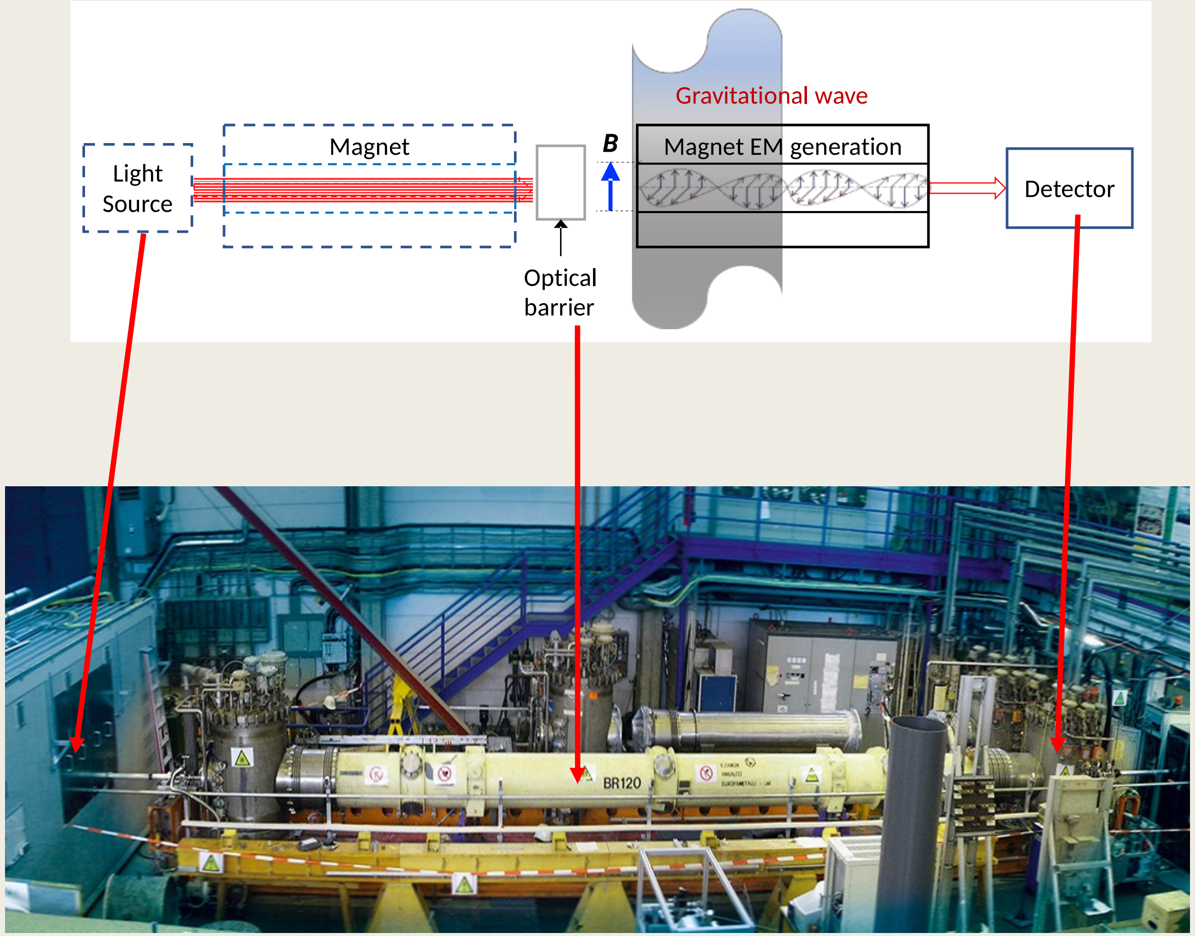
Similarity: Axion search using laboratory static magnetic fields

- Axions are generated in the magnetic field coupled to two photons.
- Axions, in the second region of the magnetic field, decay into photons.



ALPS (**A**ny-**L**ike **P**article **S**earch) DESY Germany

- Magnet provided form HERA particle accelerator working at liquid helium (4 K).
- Magnetic field: B=5 T.
- Length: L=2×4.3 m.
- Photodetector @ λ = 532 nm PIXIS CCD.
- Data acquisition 2009-2010.
- They excluded detection of any physical signal @ 95% confidence interval.



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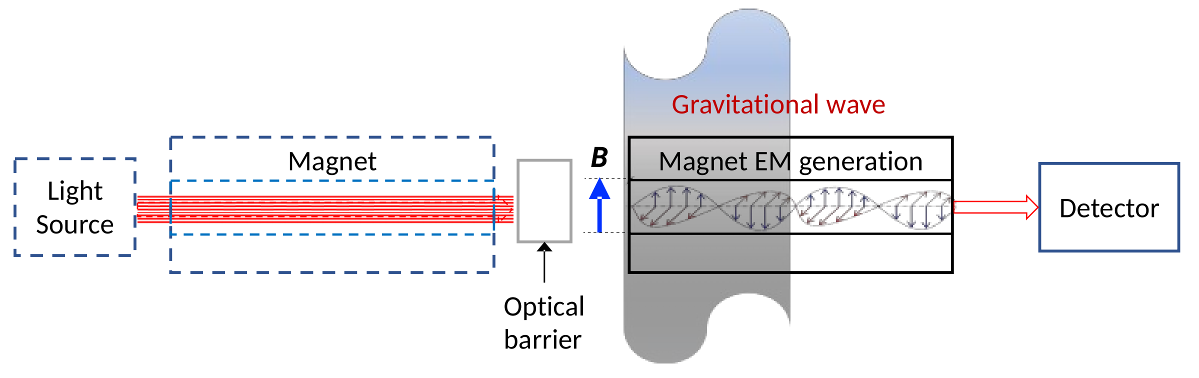
OSQAR (**O**ptical **S**earch of **Q**ED, **A**xion and photon **R**egeneration) CERN Switzerland



- Magnets provided from spare LHC particle accelerator working @ superfluid helium (2 K).
- Magnetic field Field: B = 9 T.
- Magnet length: L = 14.3 m.
- Photodetector @ 532 nm.
- Data acquisition 2014-2015.
- Excluded detection of physical signal @ 95% confidence interval.

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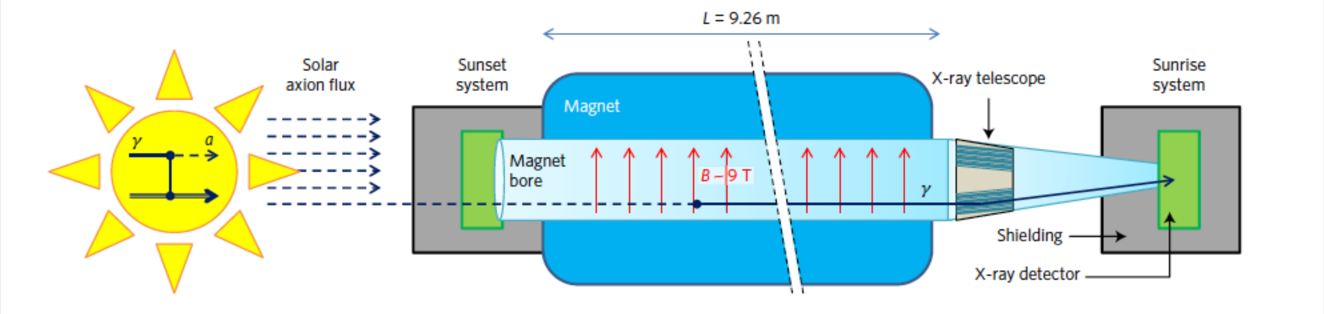
CAST (**C**ERN **A**xion **S**olar **T**elescope) CERN Switzerland



- Magnet provided from spare LHC particle accelerator working @ superfluid helium (2 K).
- Magnetic field: 9 Tesla.
- Length: 9 m.
- X-Ray detector @ 3 nm.
- Data acquisition 2013-2015.
- Excluded detection of physical signal @ 95% confidence interval.

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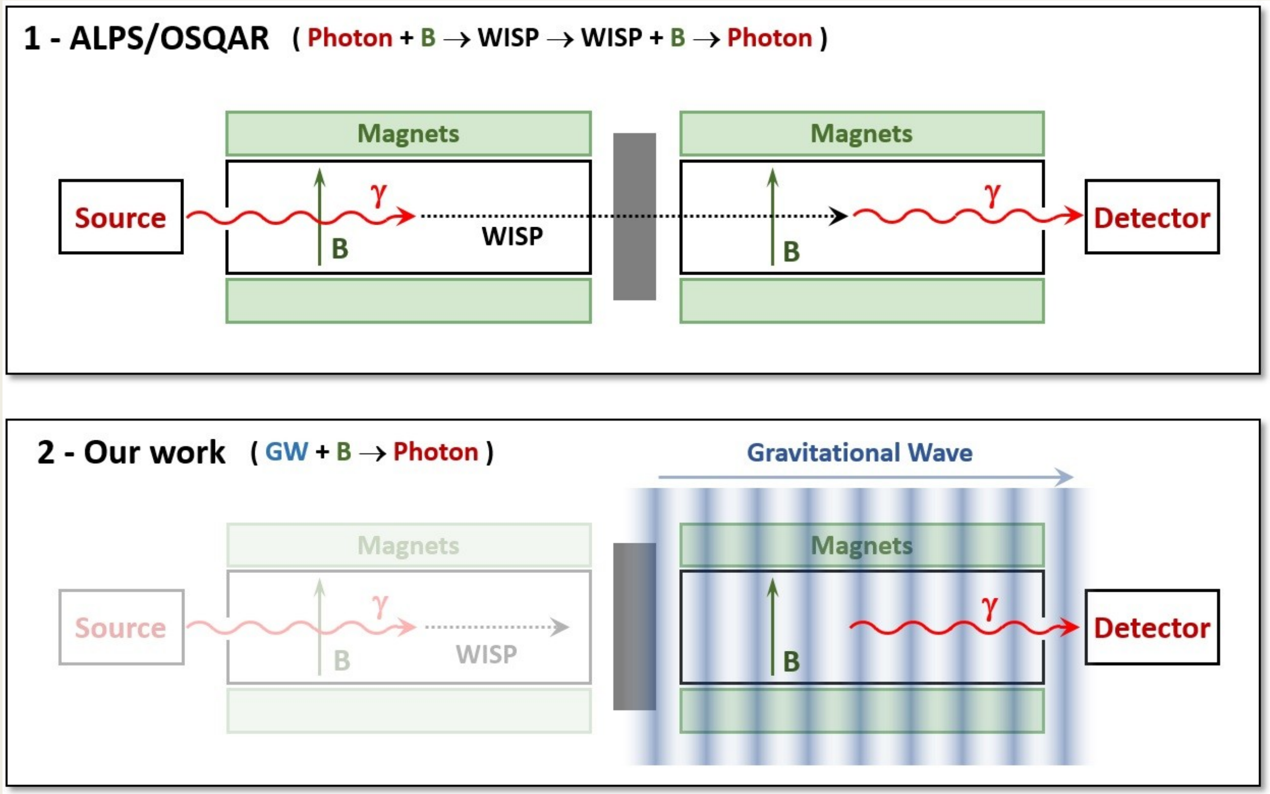
GWs upper limits: ALPS, OSQAR, CAST

Detectors

- Cannot be pointed deliberately to the emitting sources, except CAST
- GWs upper limits at Ultra-High-Frequencies (UHF): optical 5×10^{14} Hz and X-ray 10^{18} Hz

Suited sources

- Cosmological sources: stochastic, isotropic, stationary, and Gaussian gravitational-waves.
- UHF GWs candidates: Primordial black holes (PHB), thermal GWs from the Sun.

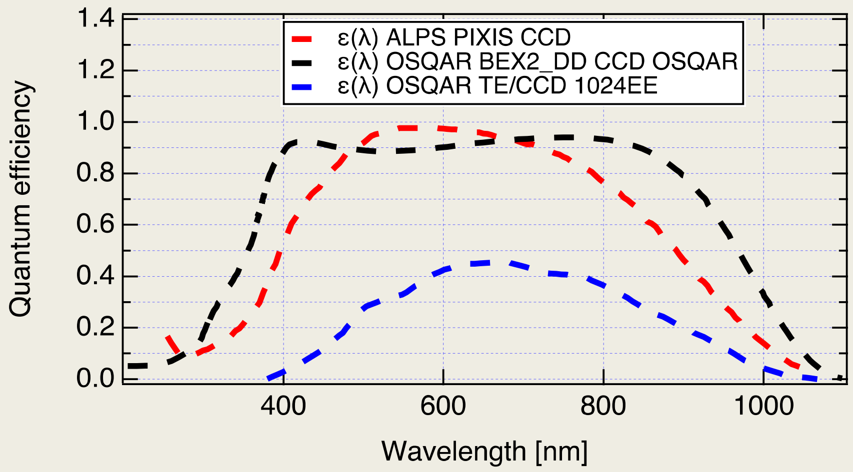


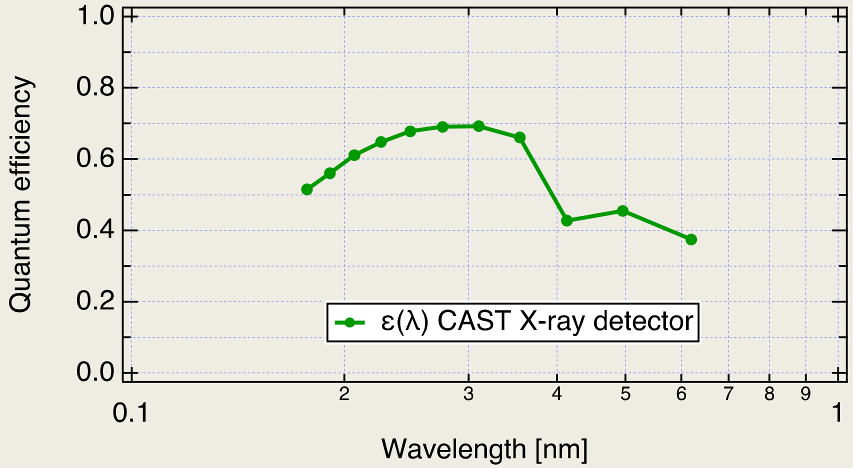
Parameters necessary to compute the characteristic amplitude

$$h_c^{\min}(0,\omega) \simeq \sqrt{\frac{4\,N_{\rm exp}}{A\,B^2\,L^2\,\epsilon_\gamma(\omega)\,\Delta\omega}} \simeq 1.6\times 10^{-16}\sqrt{\left(\frac{N_{\rm exp}}{1\ \rm Hz}\right)\left(\frac{1\ \rm m^2}{A}\right)\left(\frac{1\ \rm T}{B}\right)^2\left(\frac{1\ \rm m}{L}\right)^2\left(\frac{1\ \rm Hz}{\Delta f}\right)\left(\frac{1}{\epsilon_\gamma(\omega)}\right)}$$

- detected number of photons per second,
- cross-section of the detector,
- magnetic field amplitude,
- distance extension of the magnetic field,
- frequency of the detector
- quantum efficiency of the detector

	$\epsilon_\gamma(\omega)$	$N_{\rm exp}$ (mHz)	A ($\rm m^2$)	B (T)	L (m)	Δf (Hz)
ALPS I	see Fig 2	0.61	0.5×10^{-3}	5	9	9×10^{14}
OSQAR I	see Fig 2	1.76	0.5×10^{-3}	9	14.3	5×10^{14}
OSQAR II	see Fig 2	1.14	0.5×10^{-3}	9	14.3	1×10^{15}
CAST	see Fig 2	0.15	2.9×10^{-3}	9	9.26	1×10^{18}





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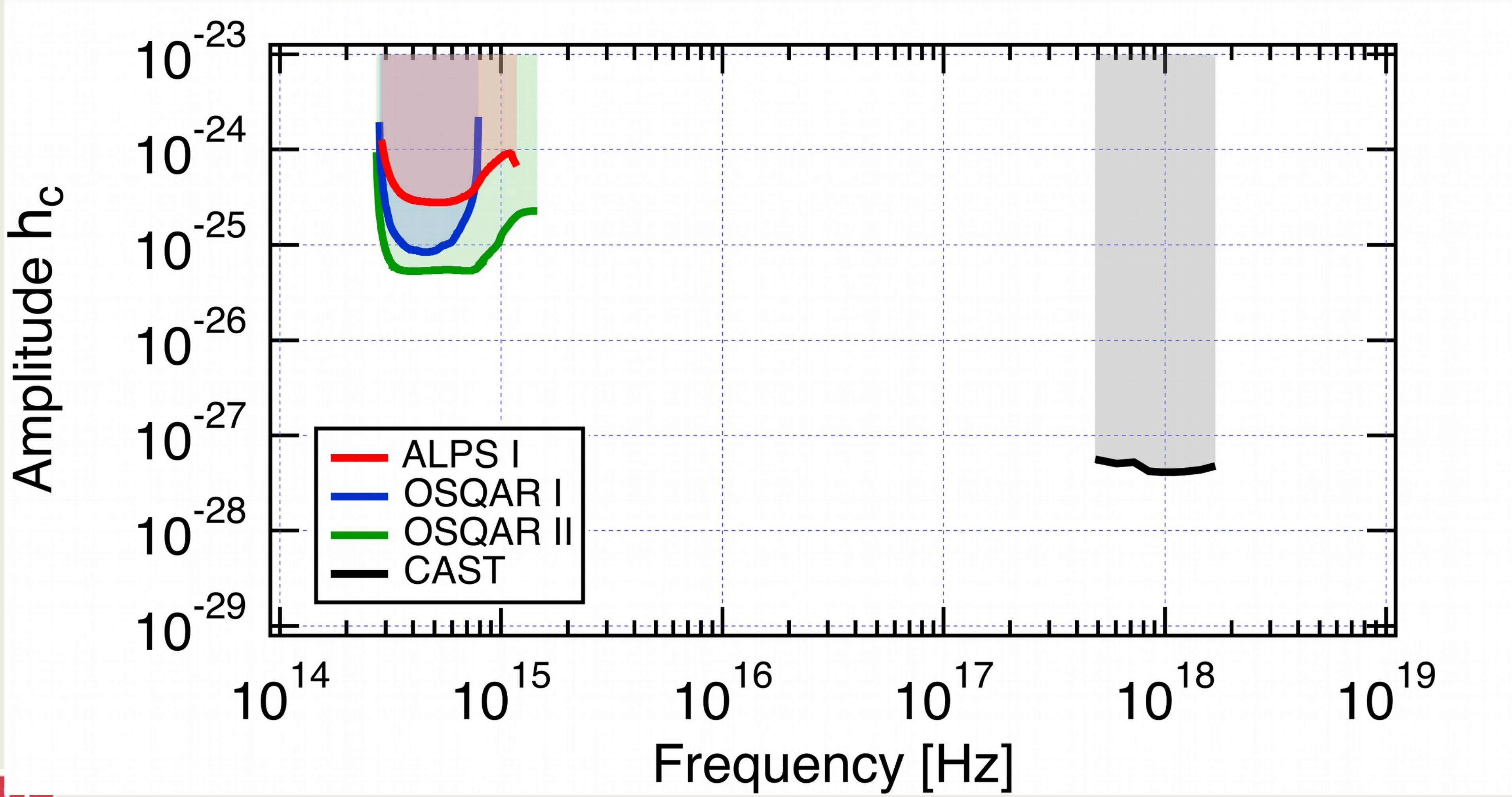
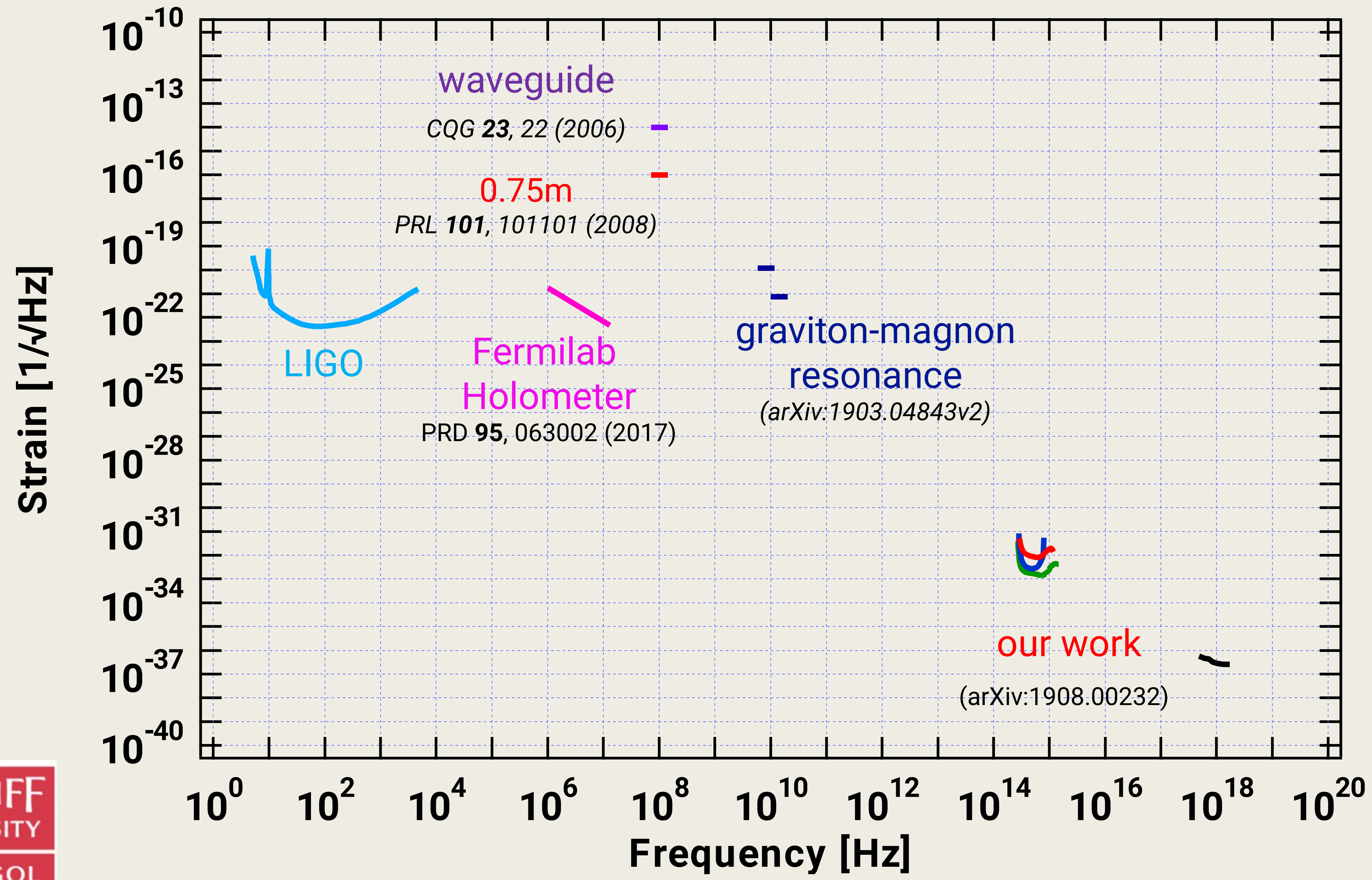
UHF GW characteristic amplitude upper limits



ArXiv 1908:00232

STRAIN UPPER LIMITS



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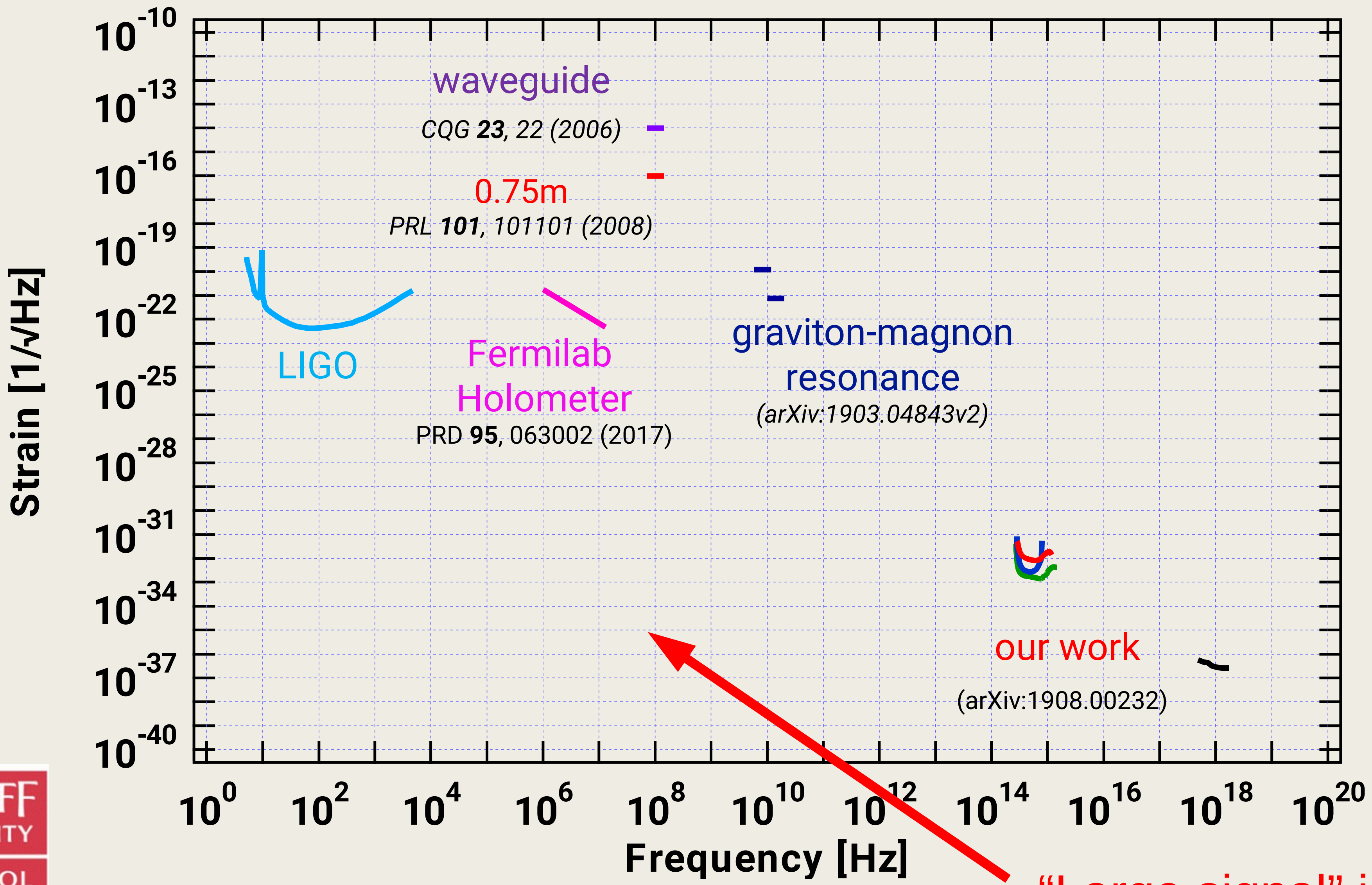
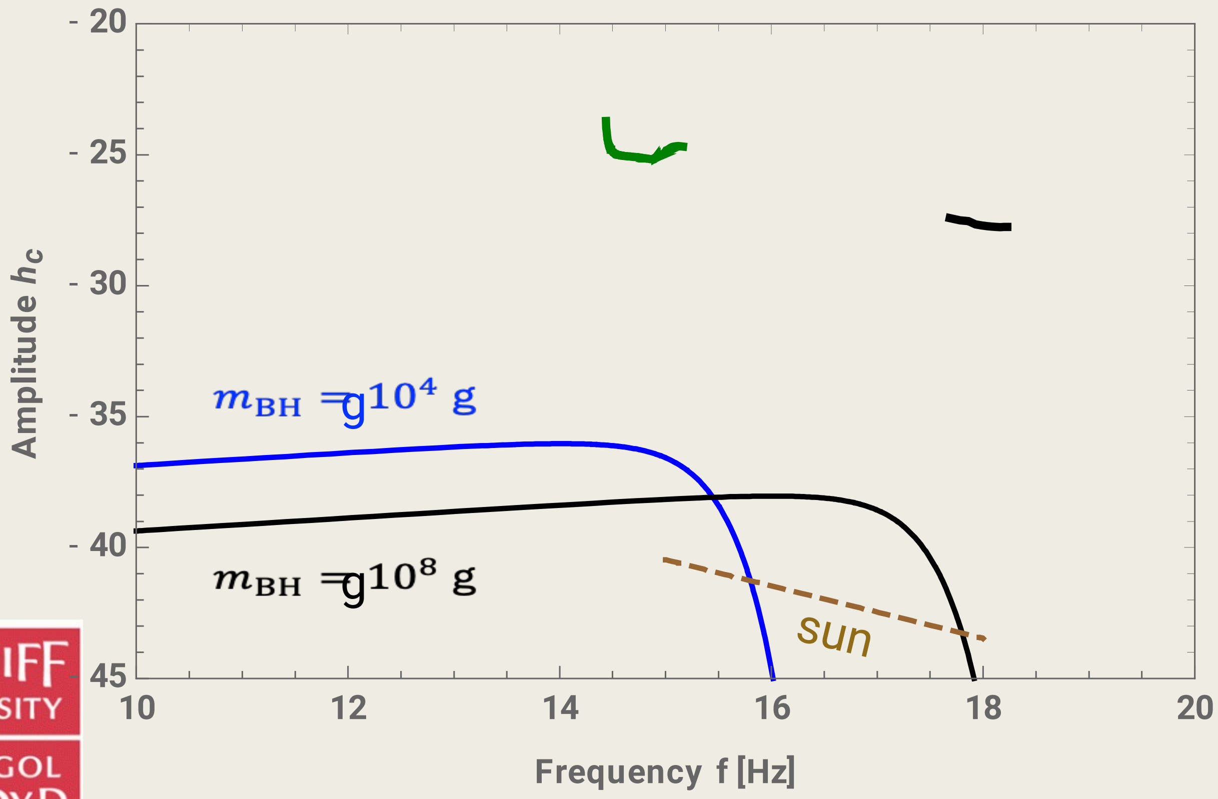
STRAIN UPPER LIMITS

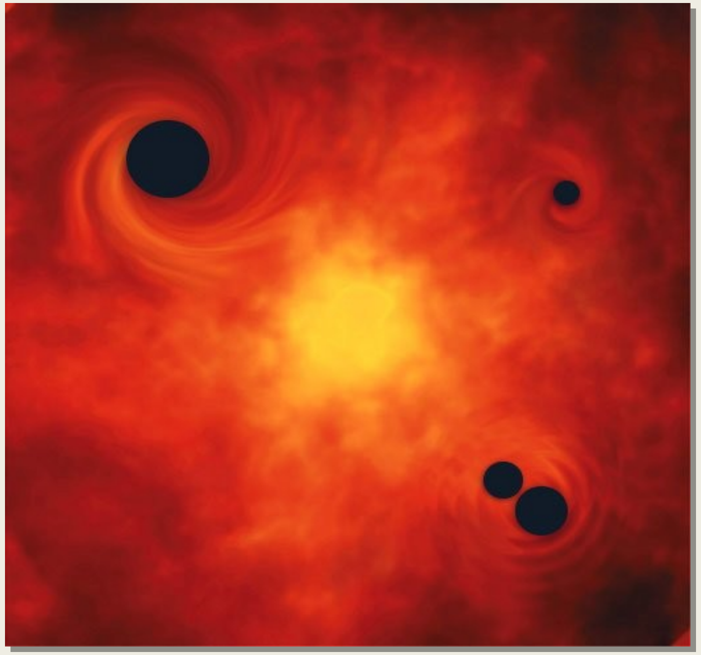


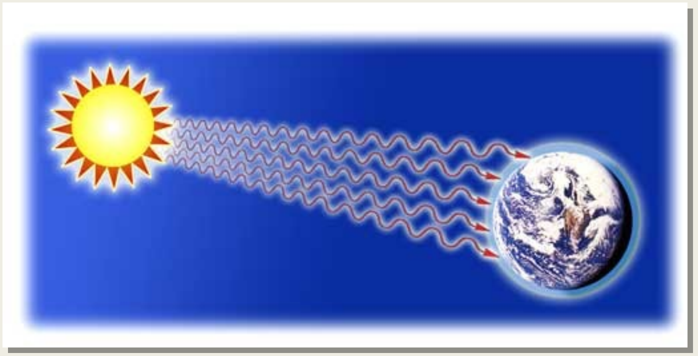
"Large signal" is here...

Primordial black hole evaporation and upper limits

- PBH evaporation: predicted stochastic isotropic UHF GWs background
- Sun: thermal activity in core generates UHF GWs.







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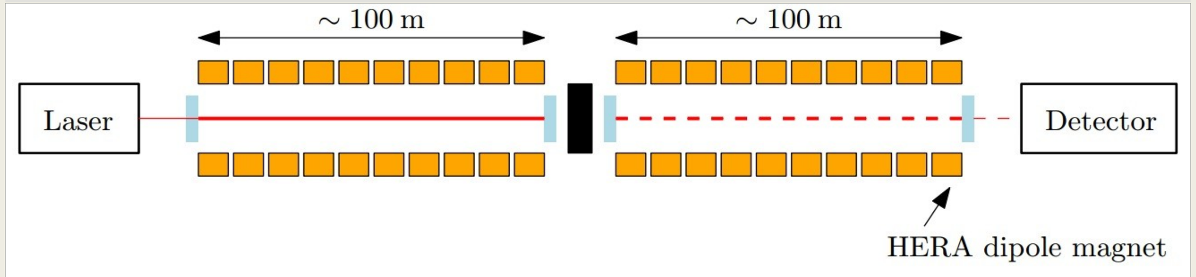
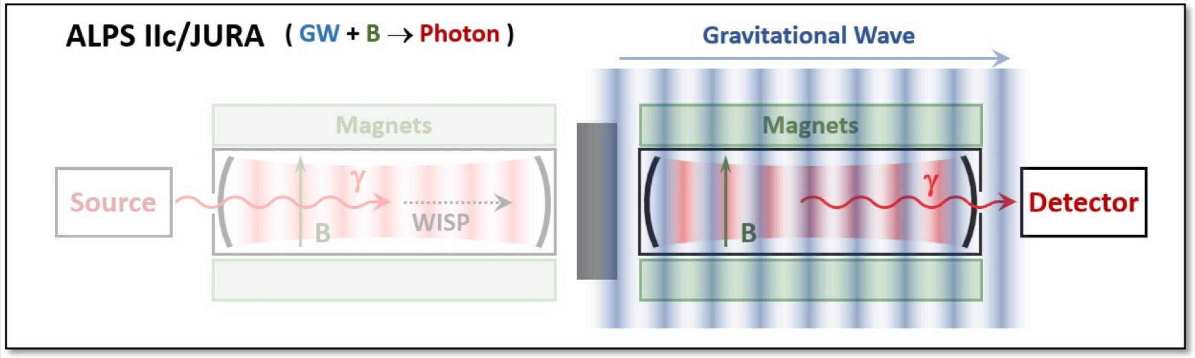
Graviton to photon mixing and future laboratory axion experiments ALPS II, JURA, IAXO

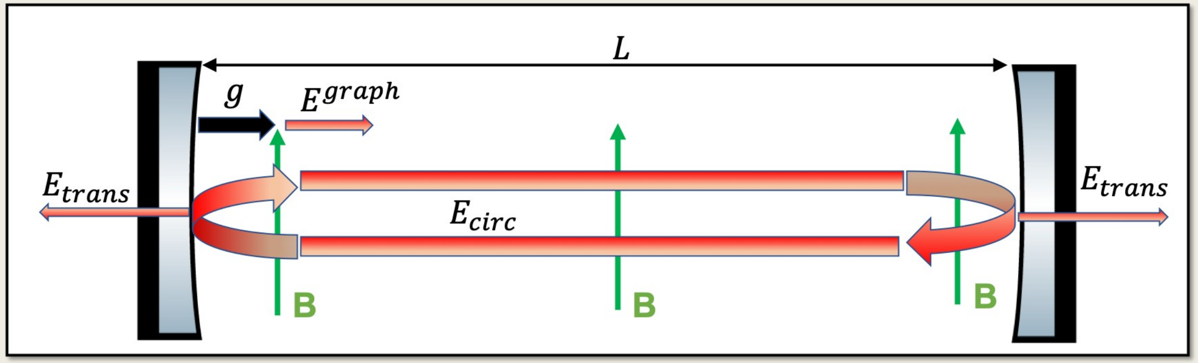
ALPS II



ALPS-IIc

Graviton to photon conversion in resonant Fabry-Perot cavity, ALPS II and JURA





$$h_c^{\mathrm{min}}(0,\omega^*) \simeq 2.8\times 10^{-16}\sqrt{\left(\frac{1}{\mathcal{F}}\right)\left(\frac{N_{\mathrm{dark}}}{1\ \mathrm{Hz}}\right)\left(\frac{1\ \mathrm{m}^2}{A}\right)\left(\frac{1\ \mathrm{T}}{B}\right)^2\left(\frac{1\ \mathrm{m}}{L}\right)^2\left(\frac{1\ \mathrm{Hz}}{\Delta f}\right)\left(\frac{1}{\epsilon_\gamma(\omega)}\right)}$$

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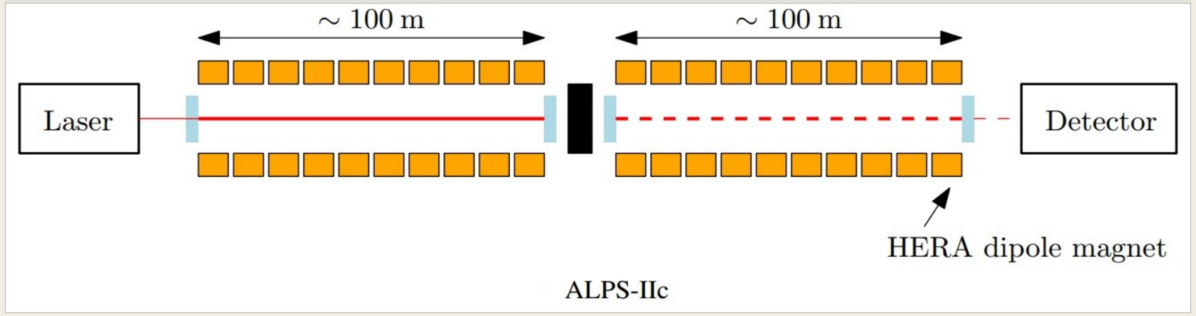
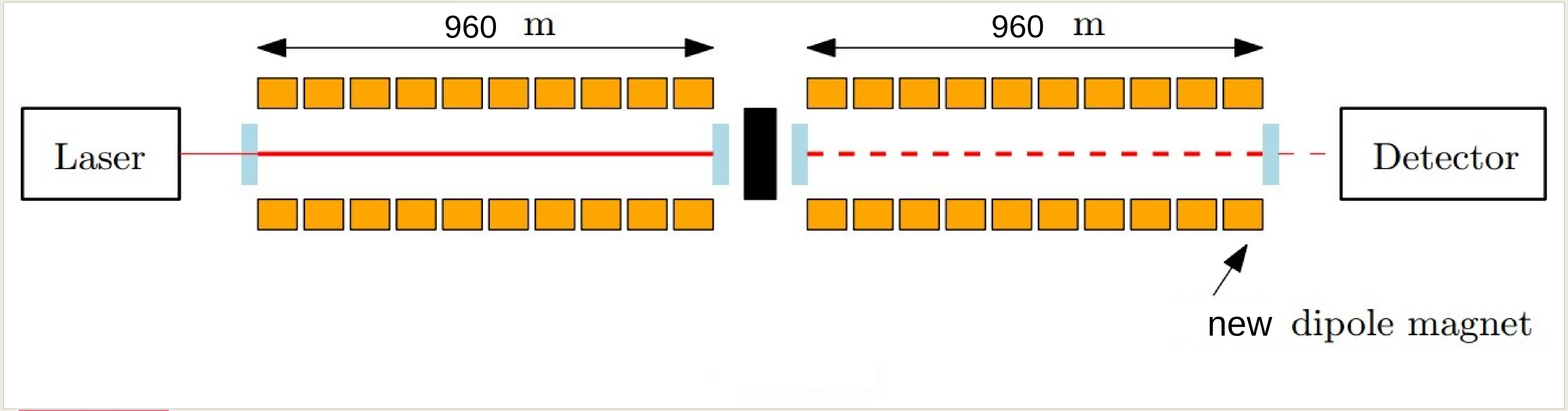
Graviton to photon mixing and future laboratory axion experiments ALPS II, JURA, IAXO

ALPS II



JURA



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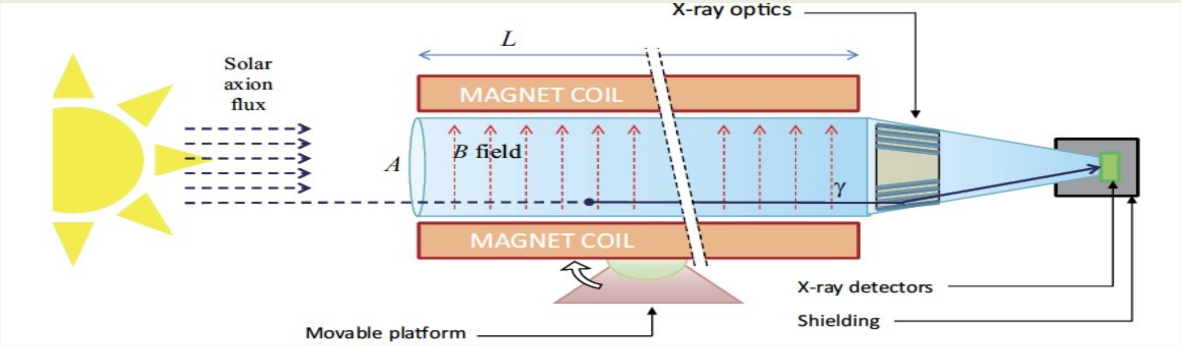
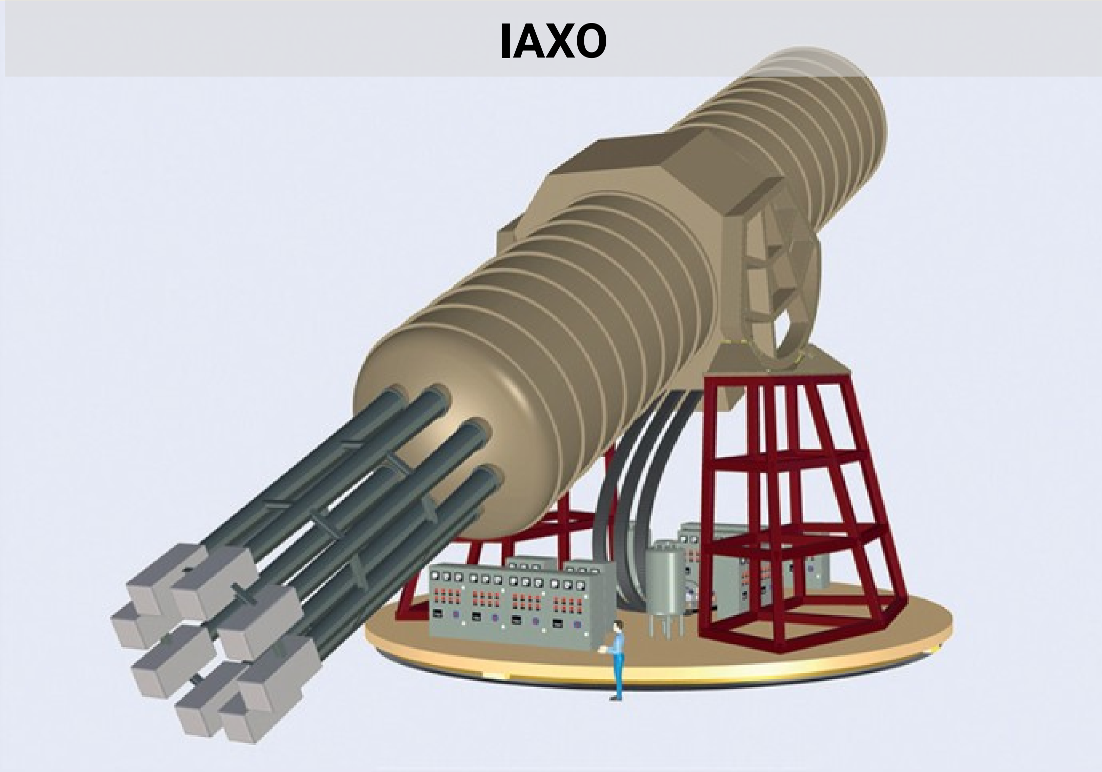
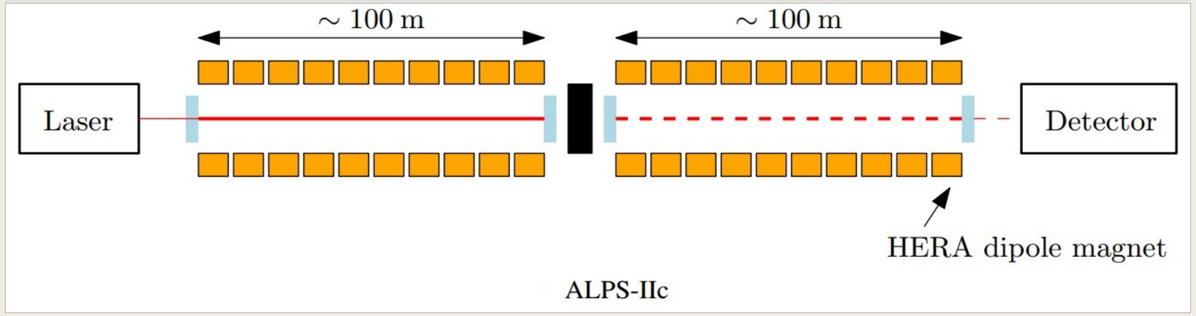
Graviton to photon mixing and future laboratory axion experiments ALPS II, JURA, IAXO

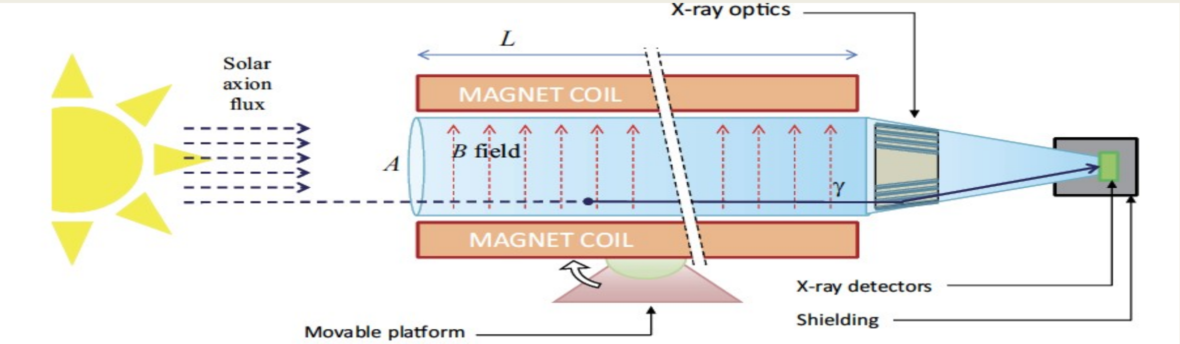




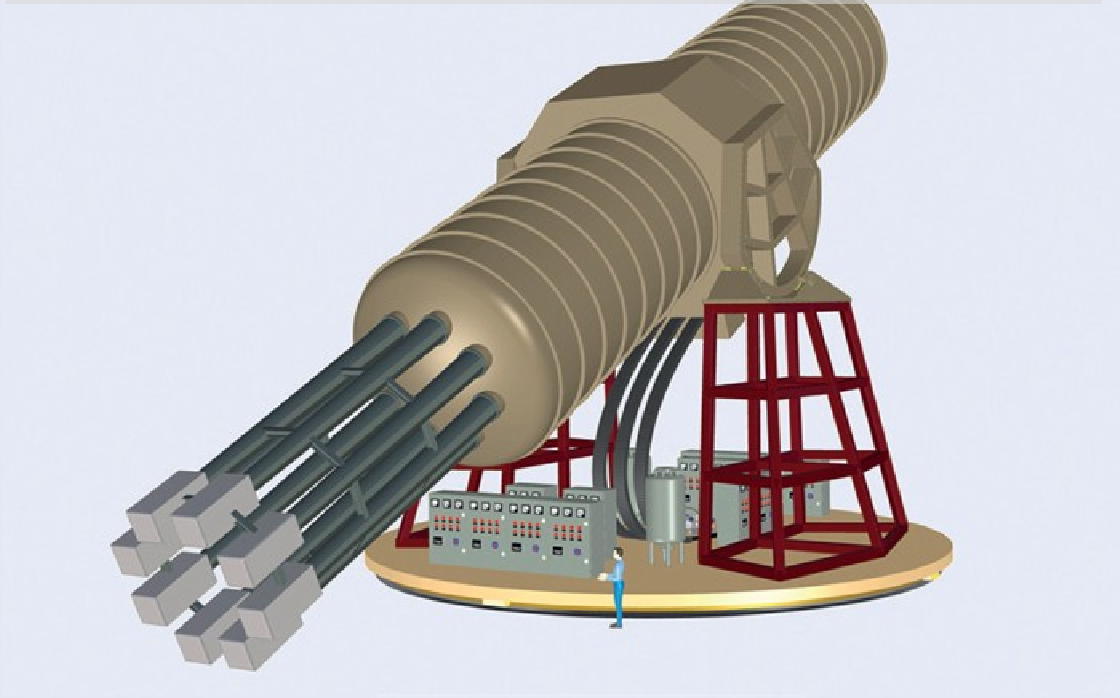
Graviton to photon mixing and future laboratory axion experiments ALPS II, JURA, IAXO

ALPS II (successor JURA)





IAXO



	η_γ	N_{dark} (Hz)	A (m^2)	B (T)	L (m)	F
ALPS IIc	0.75	$\sim 10^{-6}$	$\sim 2\times10^{-3}$	5.3	120	40 000
JURA	1	$\sim 10^{-6}$	$\sim 8\times10^{-3}$	13	960	100 000
IAXO	1	$\sim 10^{-4}$	~ 21	2.5	25	-

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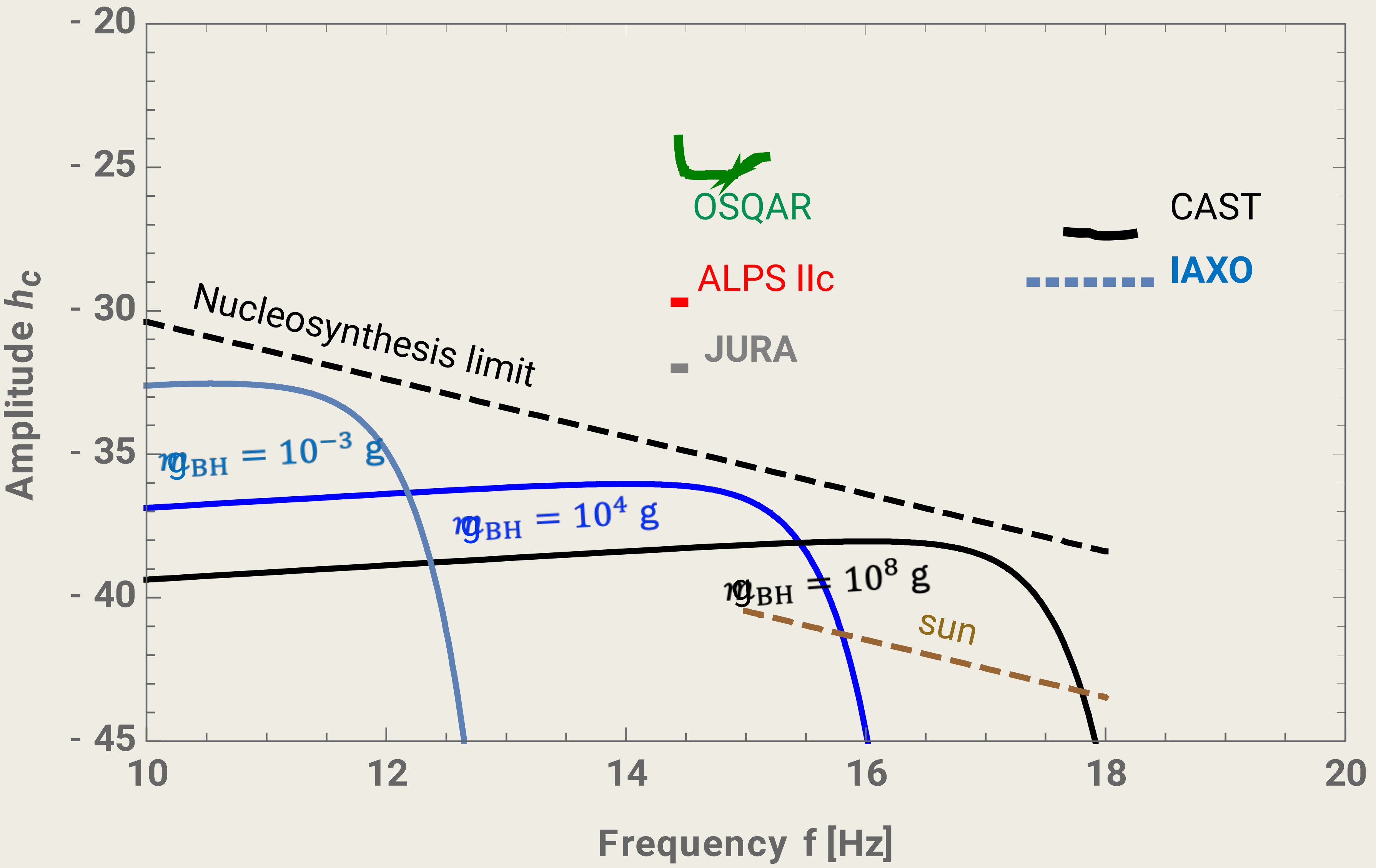
Prospects



OSQAR
CAST
ALPS IIc
IAXO
JURA
Nucleosynthesis limit
$m_{BH} = 10^{-3}$ g
$m_{BH} = 10^{4}$ g
$m_{BH} = 10^{8}$ g
sun
Amplitude h_c
Frequency f [Hz]
-20
-25
-30
-35
-40
-45
10
12
14
16
18
20

A Hertz experiment?

Weber’s / Sinsky’s idea:
GW generator and matched detector

Maybe possible for EM-GW / GW-EM conversion experiments?

IOP Publishing | Royal Swedish Academy of Sciences Physica Scripta

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Gravitational Hertz experiment with electromagnetic radiation in a strong magnetic field

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Abstract

A brief review of the principal ideas in respect of high frequency gravitational radiation generated and detected in laboratory conditions is presented. Interaction of electromagnetic and gravitational waves in a strong magnetic field is considered as a more promising variant of the laboratory GW-Hertz experiment. The formulae of the direct and inverse Gertsenshtein–Zeldovich effect are derived. Numerical estimates are given and a discussion of the possibility of observation of these effects in a laboratory is carried out.

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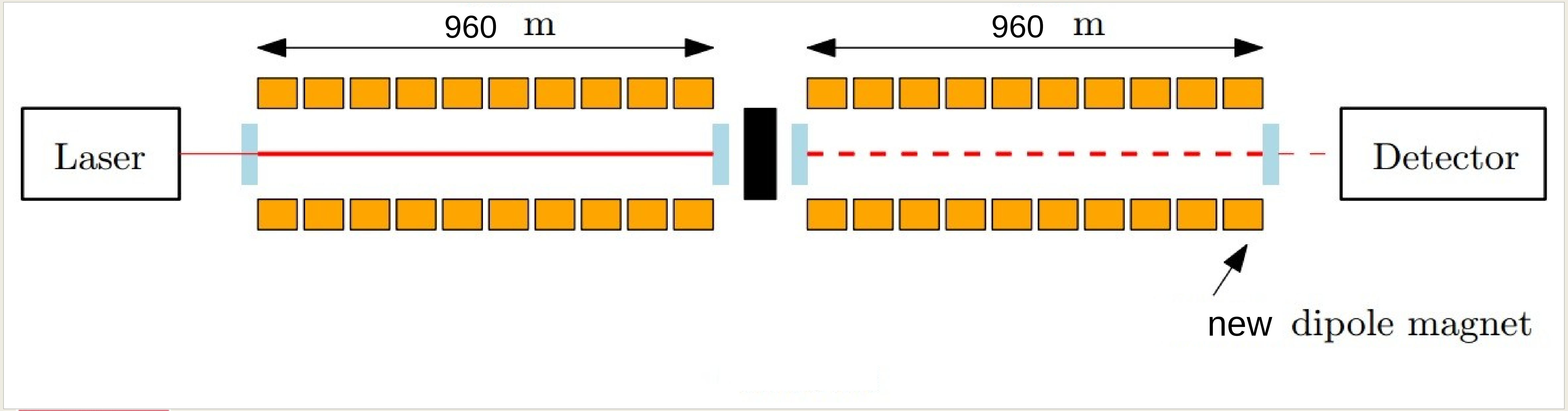
JURA could get close to detecting its *generated* gravitational waves

JURA



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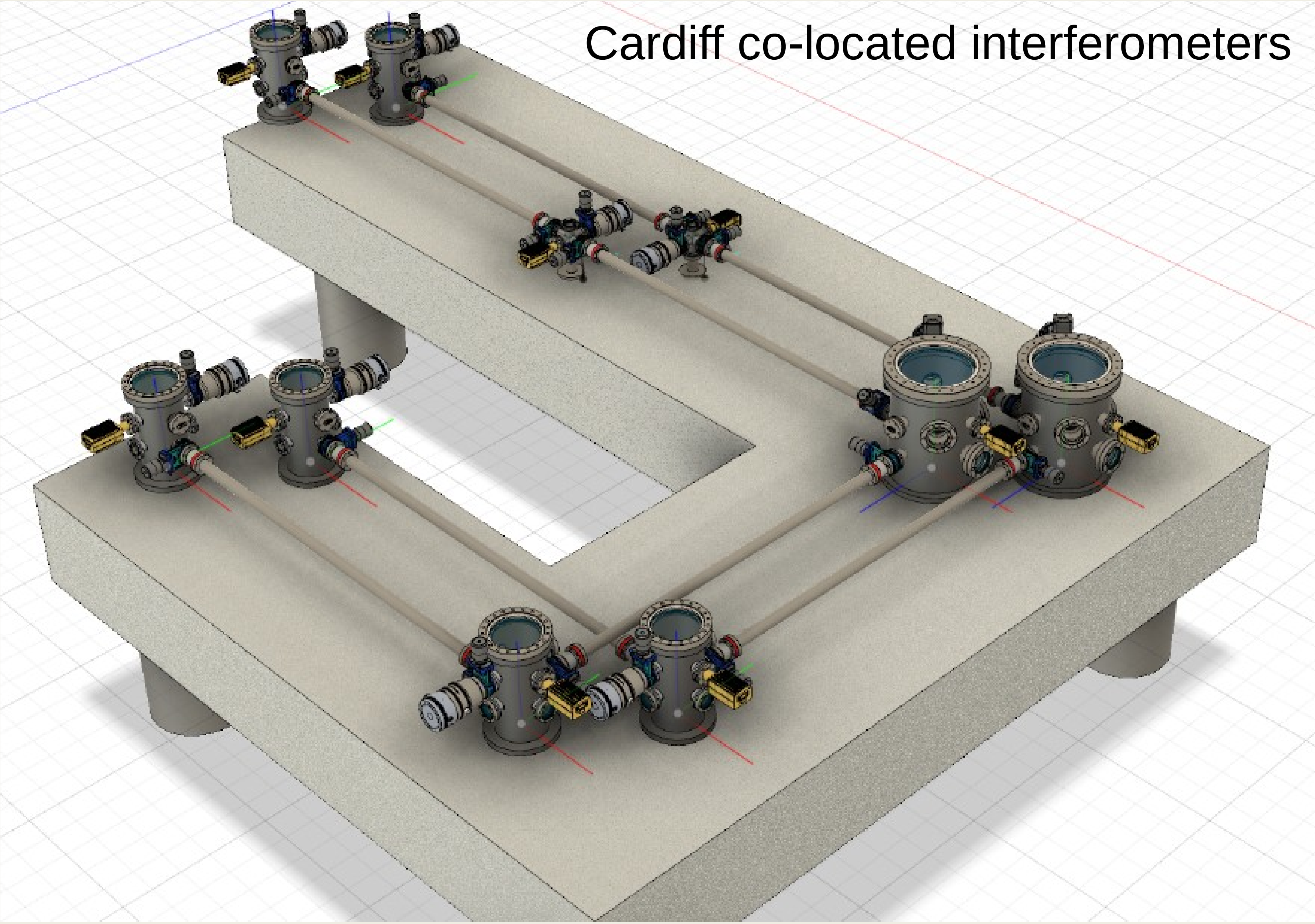
Interferometry up to ~100MHz

A case for co-located interferometry
for cross-correlation studies

Cardiff co-located interferometers



CAD Layout: A. Ejlli

Cardiff co-located interferometers

Multi-purpose facility for correlated interferometry:

- Technology development (squeezing and entangled squeezing for correlated interferometry)
- Quantization of space-time
- Dark matter searches
- High-frequency gravitational waves (1 - 100 MHz)

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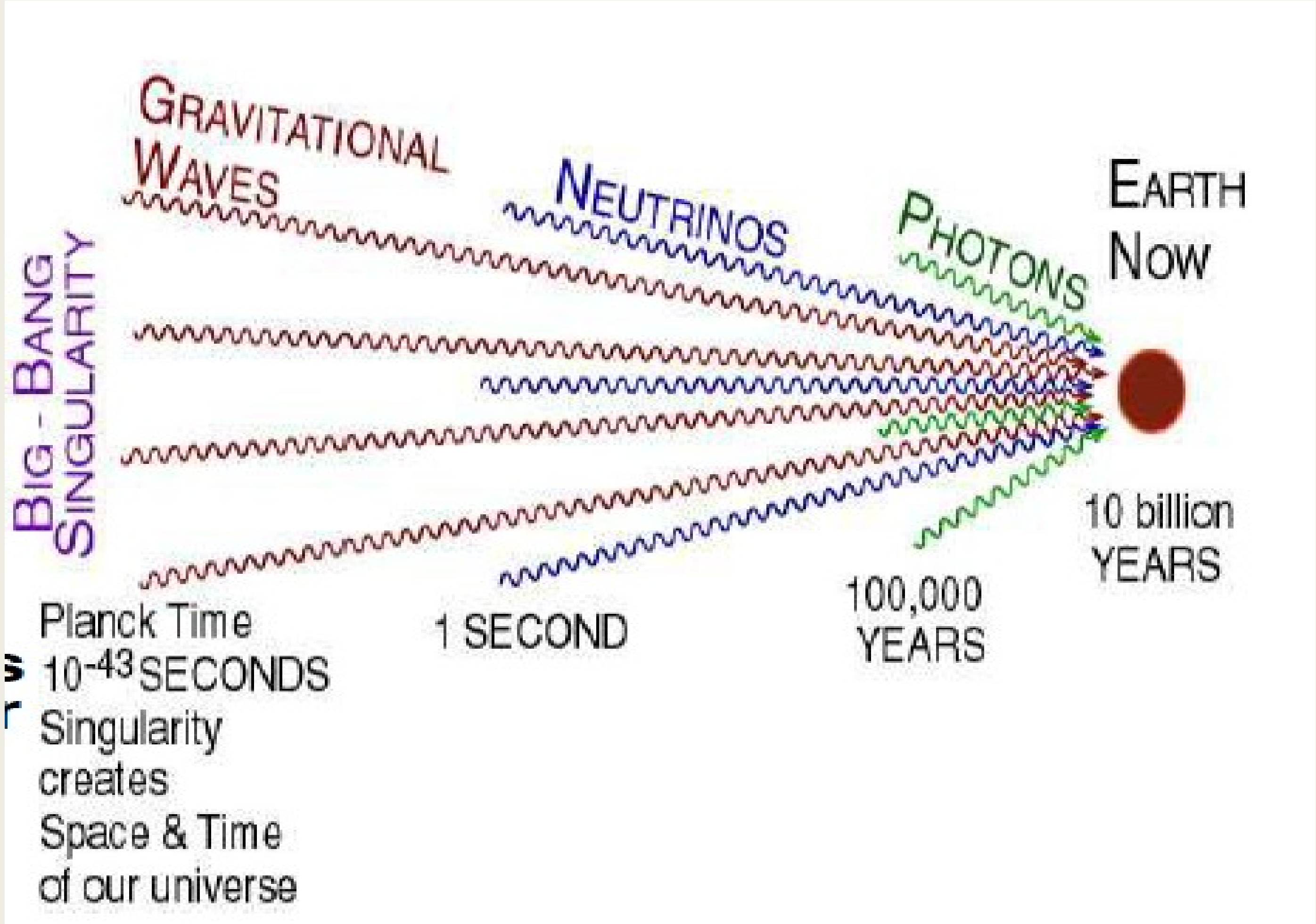
Conclusions



- We set upper limits on stochastic UHF GWs using data of laboratory axion search experiments.
- The upgraded ALPS II, JURA, and IAXO are potential infrastructure for the stochastic UHF GWs detection.
- UHF GWs of PBH evaporation are an investigation at the very early universe and observation at the Planck Scale.

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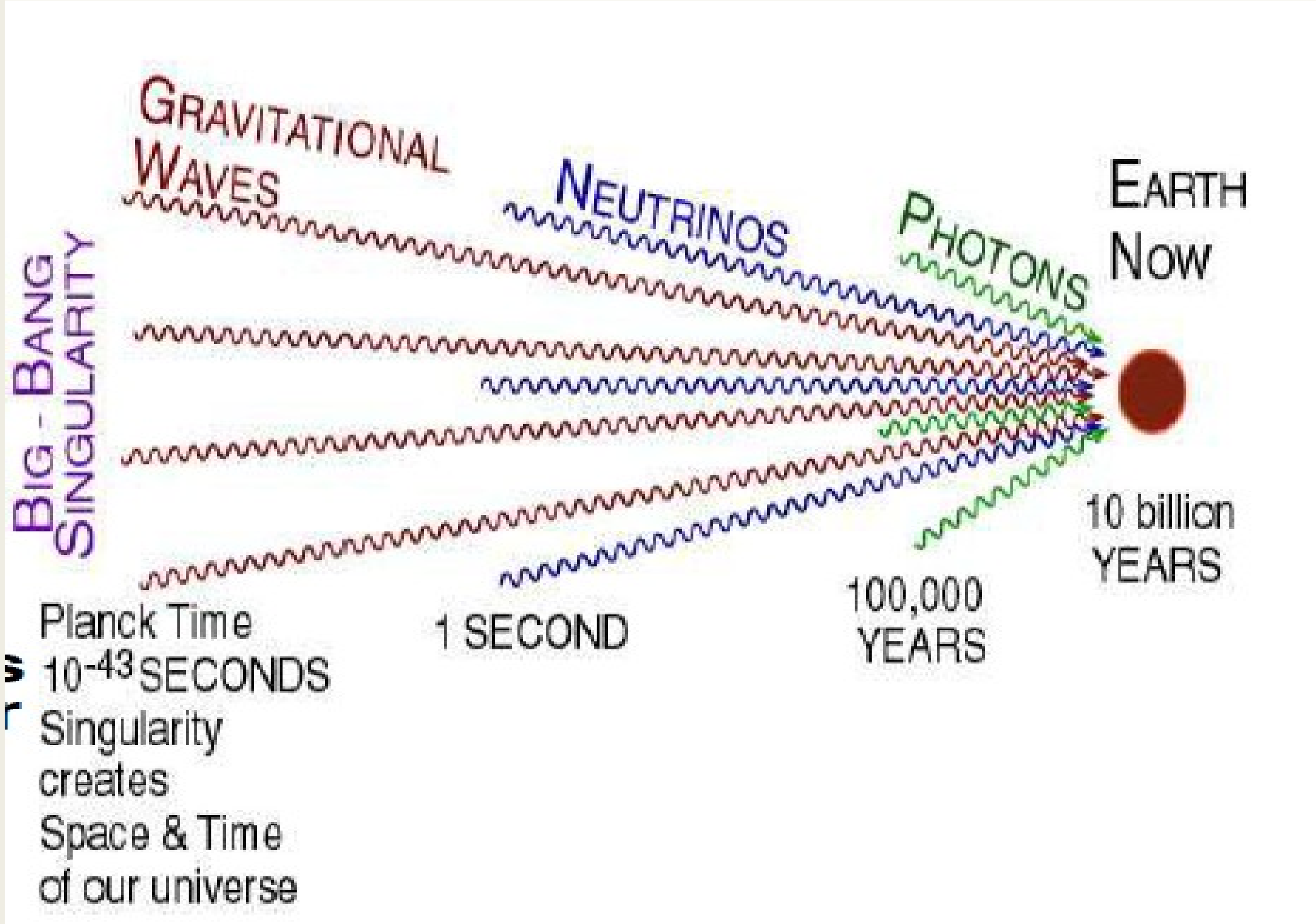
Questions



- Should we be discouredged by being many orders of magnitude away from meaningful sensitivities?
- What do you think about the value of a Hertz experiment?
- Could funding be motivated for magnetic conversion detectors (as dedicated facilities or at least modifications of existing facilities)?