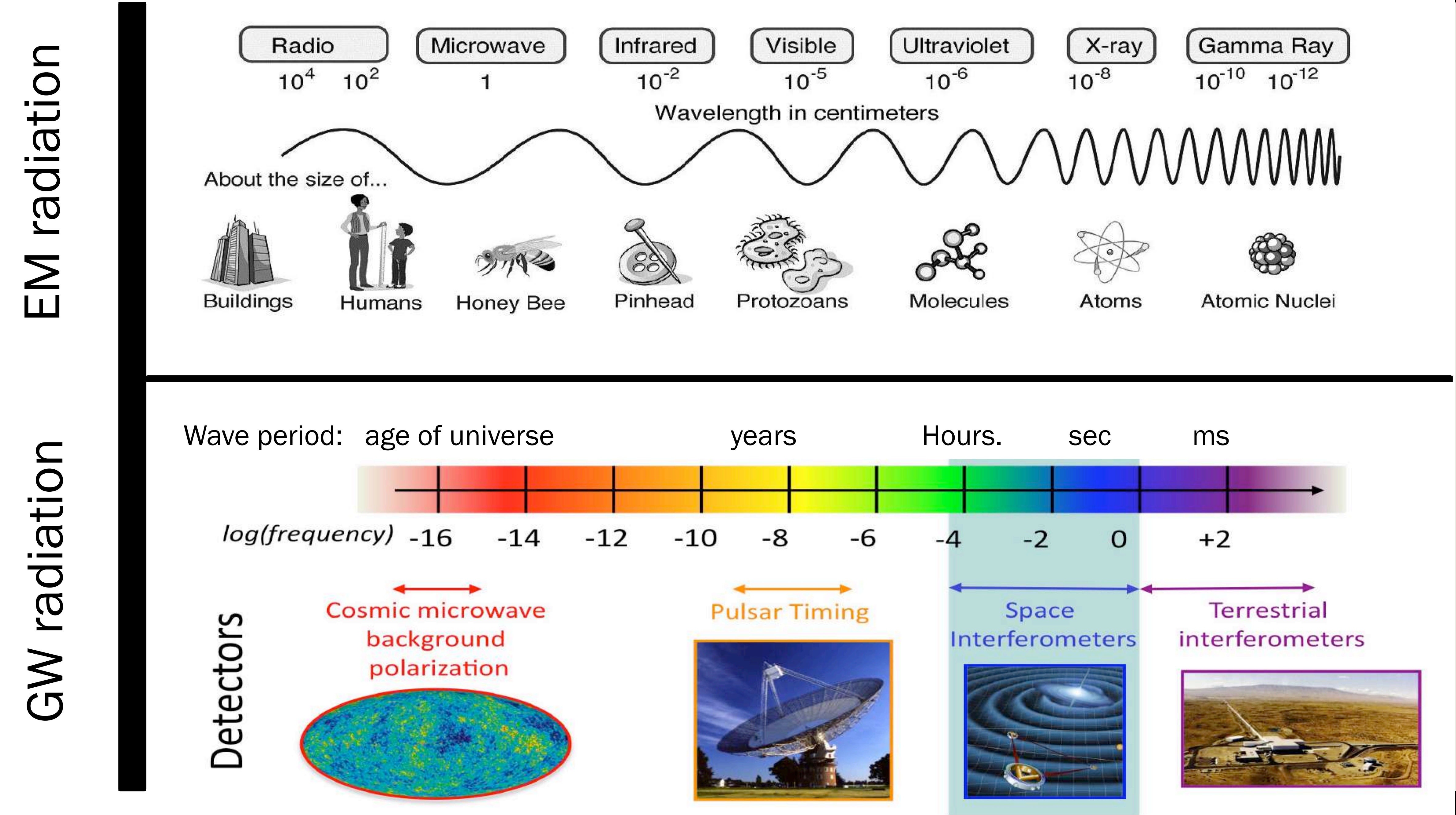
GRAVITON-PHOTON MIXING AND FUTURE LABORATORY AXION SEARCHES

Aldo Ejlli

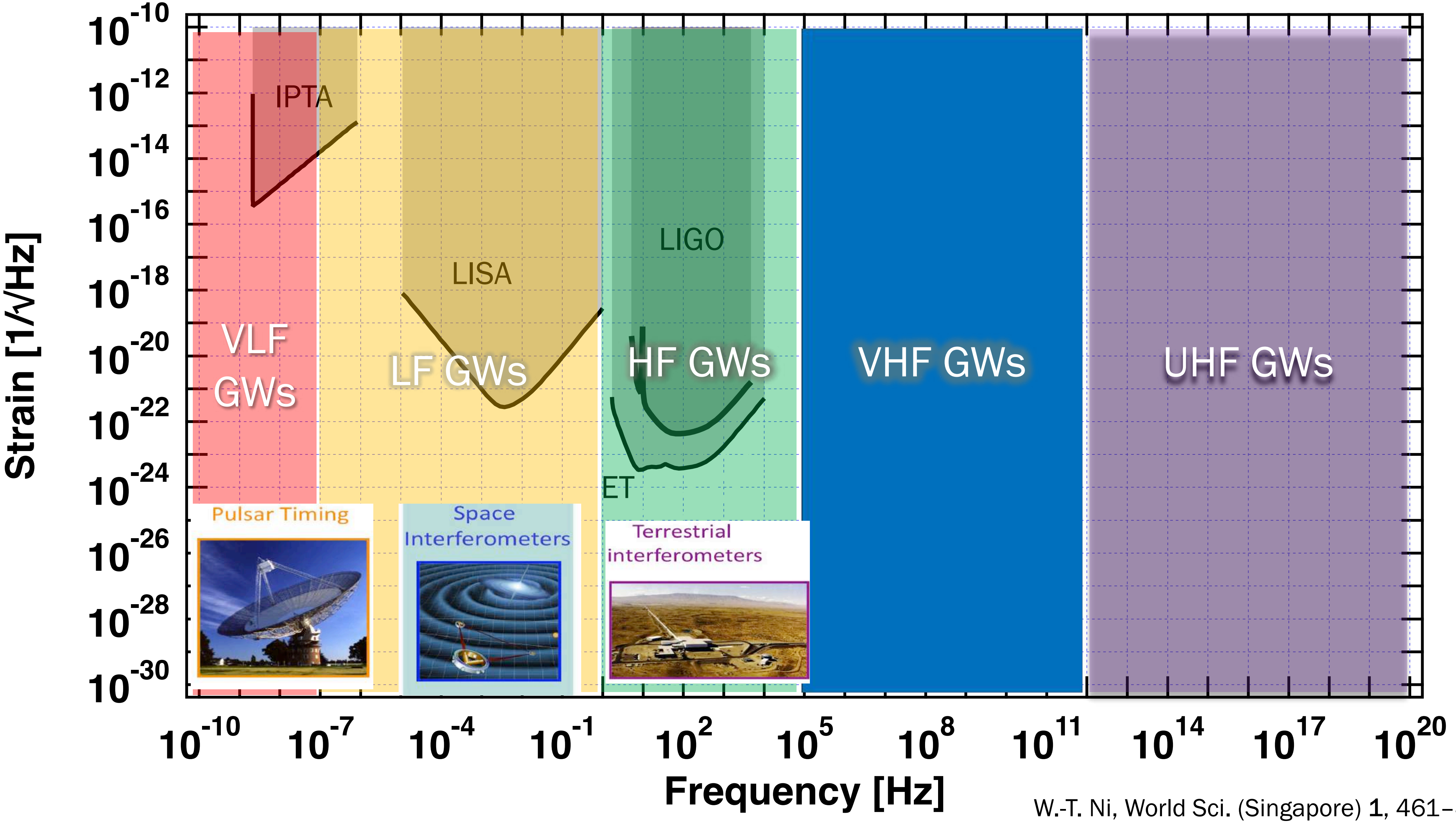
Particle Physics Seminar University of Birmingham

02/02/2022

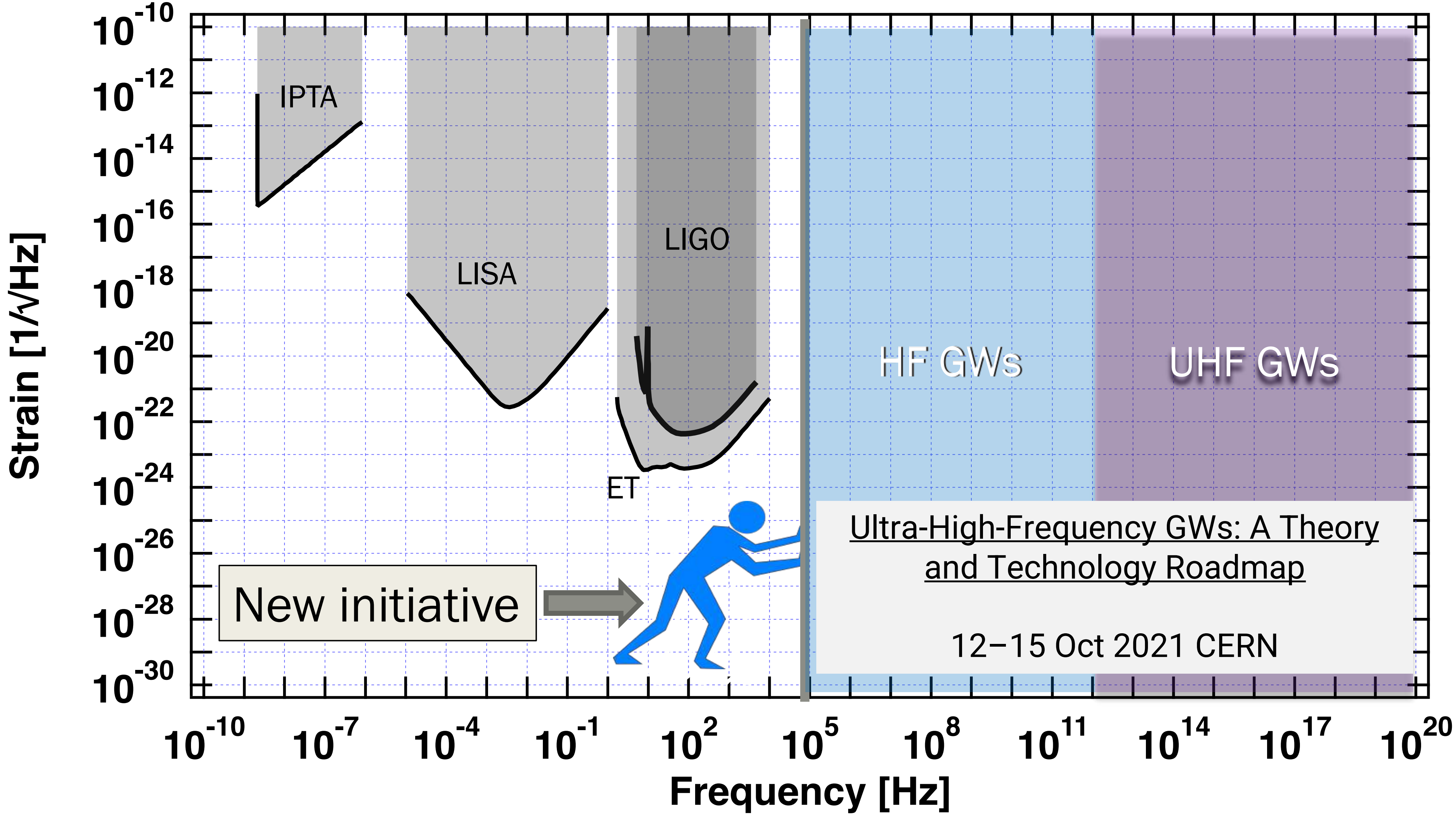
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

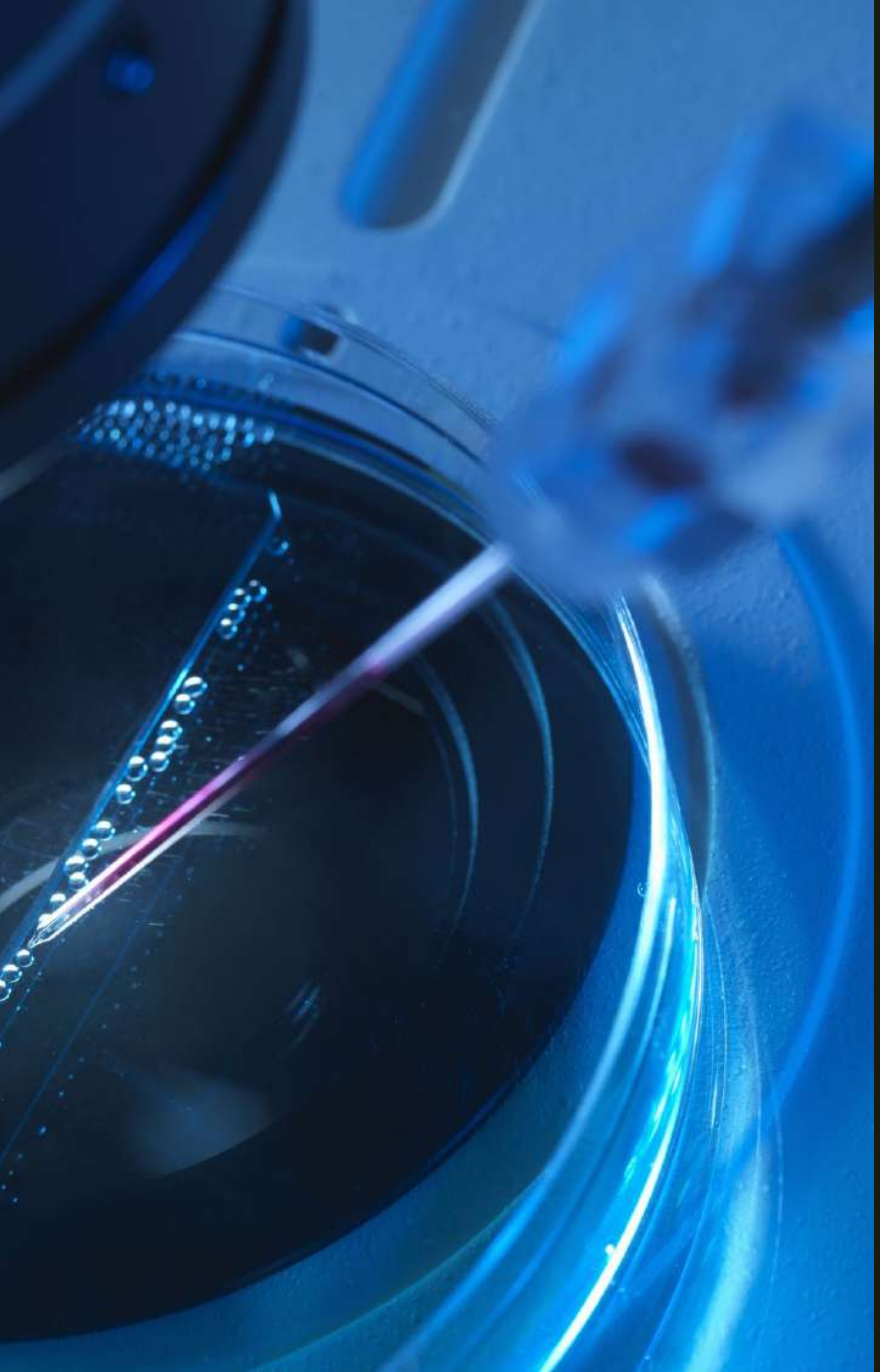

EM radiation
Radio
10^4 10^2
Microwave
1
Infrared
10^-2
Visible
10^-5
Ultraviolet
10^-6
X-ray
10^-8
Gamma Ray
10^-10 10^-12
Wavelength in centimeters
About the size of...
Buildings
Humans
Honey Bee
Pinhead
Protozoans
Molecules
Atoms
Atomic Nuclei
GW radiation
Wave period: age of universe
years
Hours.
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

Definition



W.-T. Ni, World Sci. (Singapore) 1, 461–464 (2016)


Strain [1/√Hz]
Frequency [Hz]
IPTA
LISA
LIGO
ET
HF GWs
UHF GWs
New initiative
Ultra-High-Frequency GWs: A Theory and Technology Roadmap
12–15 Oct 2021 CERN



GW UHF: new experimental proposals

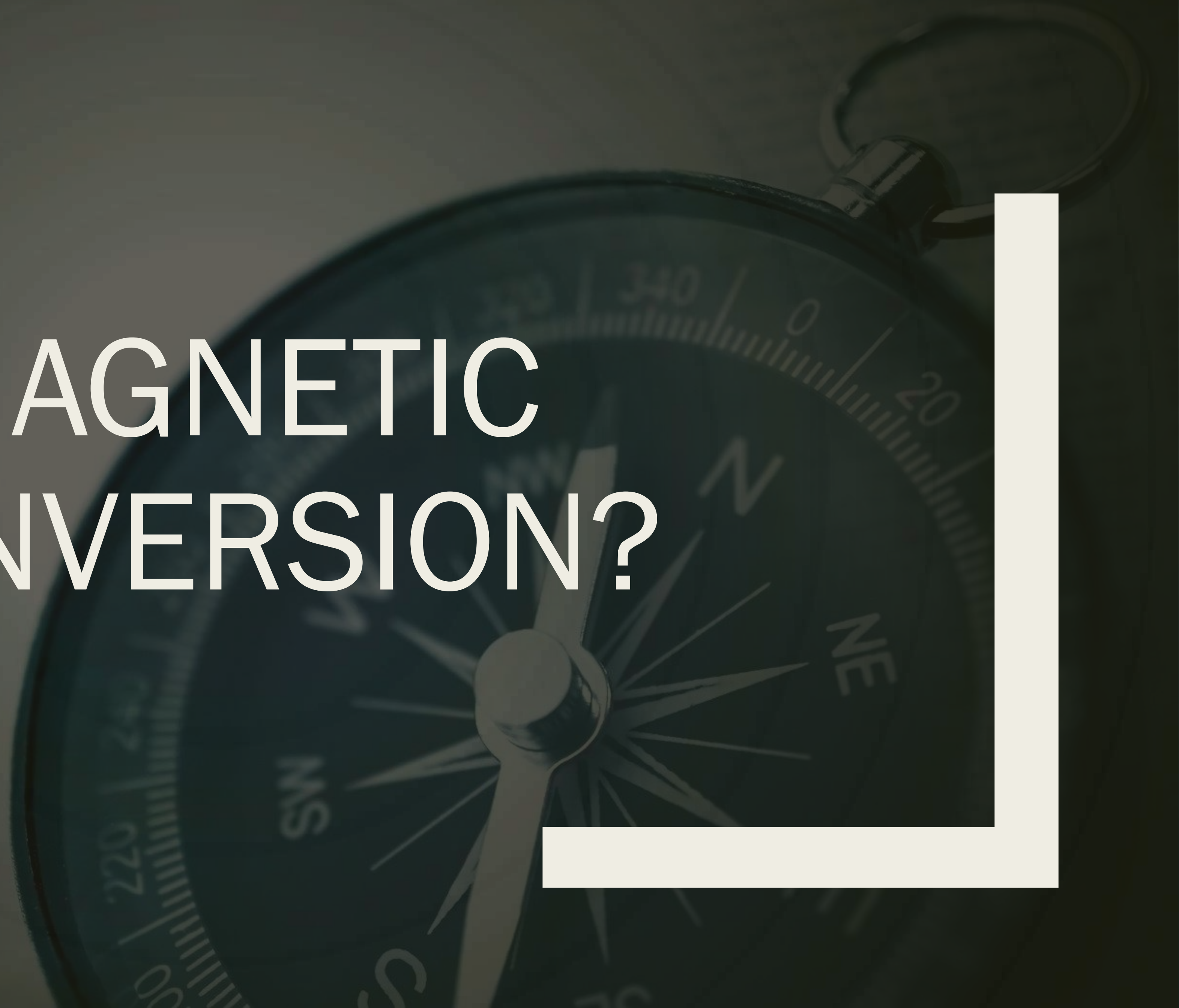
- Laser interferometers
- Optically levitated sensors
- Polarisation rotation
- Microwave resonant cavities
- GW magnon resonance
- Magnetic conversion: inverse Gertsenshtein effect
- ...

Outline

- Magnetic conversion of GWs in static magnetic field
- Axion experiments and magnetic conversion
- Experimental UHF GWs upper limits
- Prospect of UHF GWs in upgraded axion experiments
- HF GWs using interferometry
- Conclusions

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

MAGNETIC CONVERSION?



Magnetic conversion: not a new idea

Electromagnetic waves (photons) can transform into gravitational waves (gravitons) in the presence of a constant external magnetic field, Gertsenshtein (1962), Lupanov (1967).

The reverse process $g \to \gamma$ was considered by Mitskevich (1969), Boccaletti, De Sabbata, Fortini and Gualdi (1970), Zel'dovich (1973) etc.

For an extended region of a magnetic field in vacuum, there are coherent oscillations of GW in EM and vice versa in complete analogy with neutrino oscillations.

Credit Mike Cruise

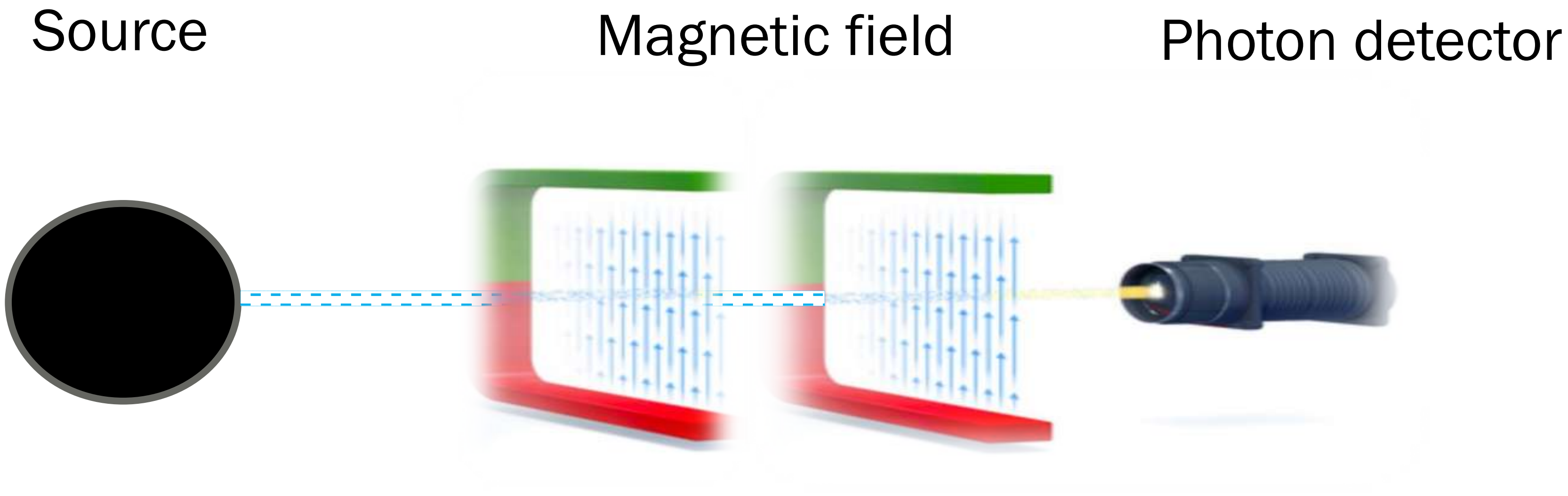
Laboratory magnetic conversion detection

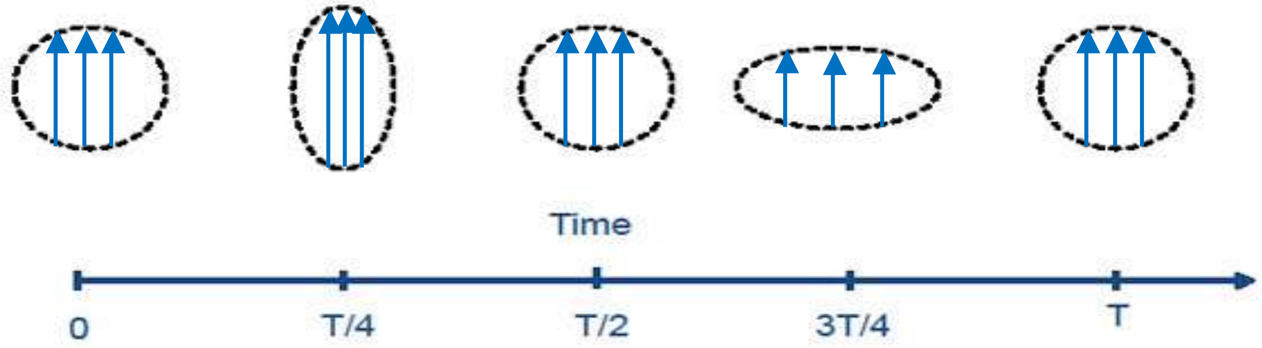
- Examples of an experimental conceptual design Prof. Mike Cruise
- Requirements: single photon detectors, aperture, field strength, cross section and directionality.

Class. Quantum Grav. 29 (2012) 095003 (12pp)

Magnetic conversion (Inverse Gertsenshtein effect)

- Gravitational-wave propagating in magnetic fields convert into photons.
  Gertsenshtein, Sov. Phys., JETP 14, 84 (1962), G. A. Lupanov JETP 25, 76 (1967)





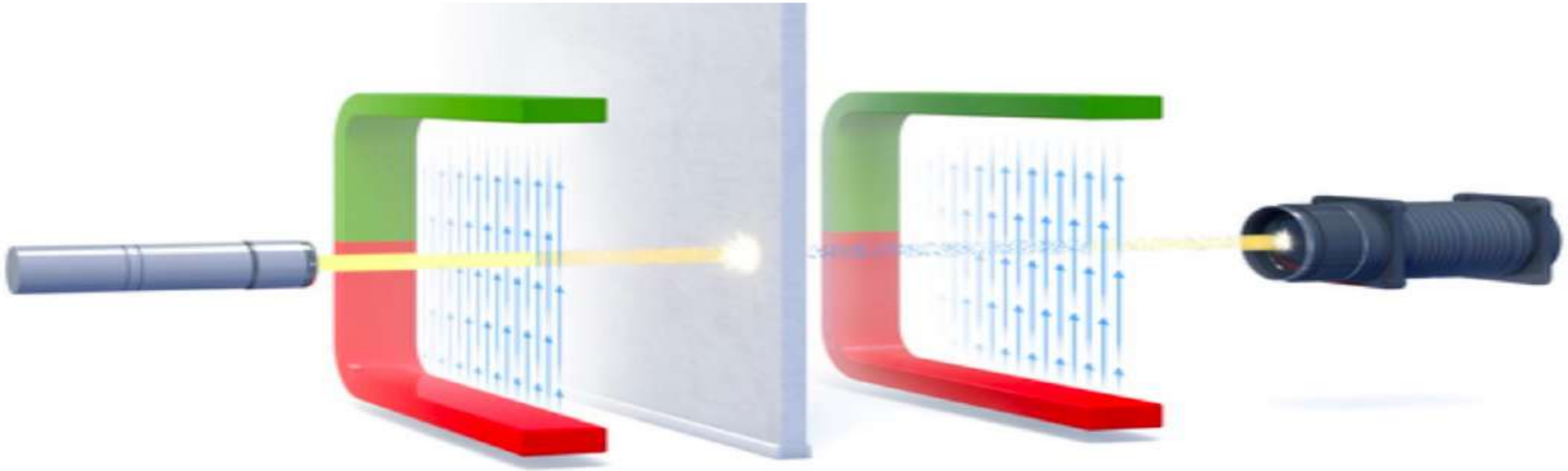
$$|h_{\mathrm{ij}}|\mathbf{B}_{\mathrm{ext}}$$

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

AXION EXPERIMENTS

Axion search using laboratory static magnetic fields

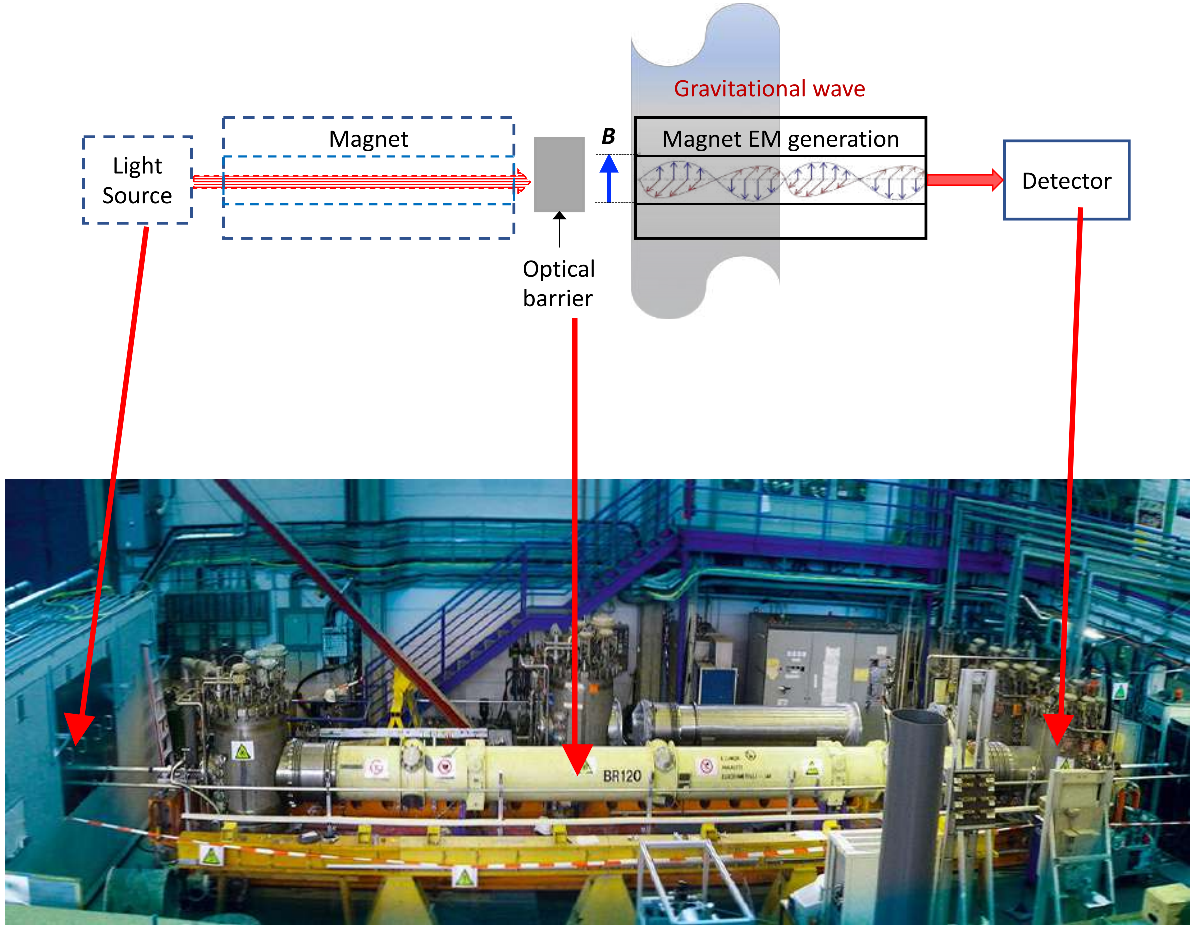
- Axions are generated in the magnetic field coupled to two photons.
- Axions, in the second region of the magnetic field, decay into photons.



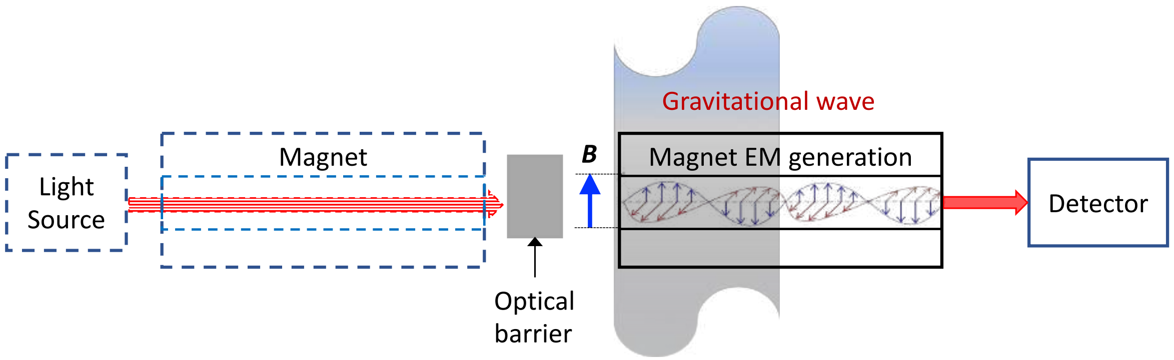
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

ALPS (Axion-Like Particle Search) 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 @ $\lambda = 532$ nm PIXIS CCD.
- Data acquisition 2009-2010.
- Excluded detection @ 95% confidence interval.



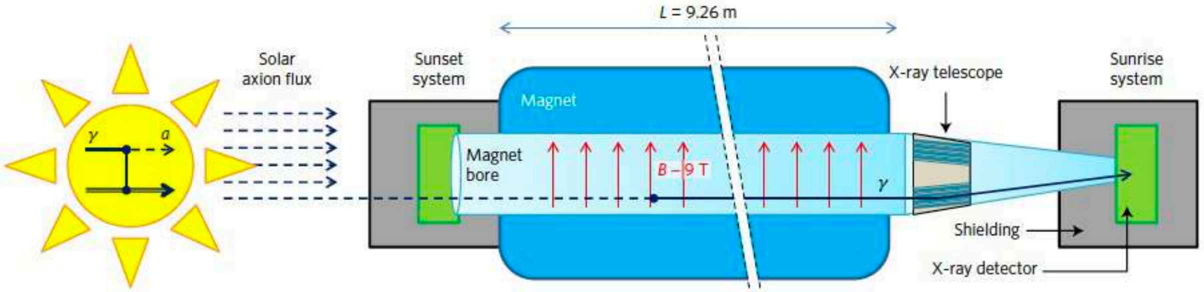
OSQAR (Optical Search of QED, Axion and photon Regeneration) CERN Switzerland



- 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 @ $\lambda = 532$ nm.
- Data acquisition 2014-2015.
- Excluded detection @ 95% confidence interval.

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

CAST (CERN Axion Solar Telescope) CERN Switzerland



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

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

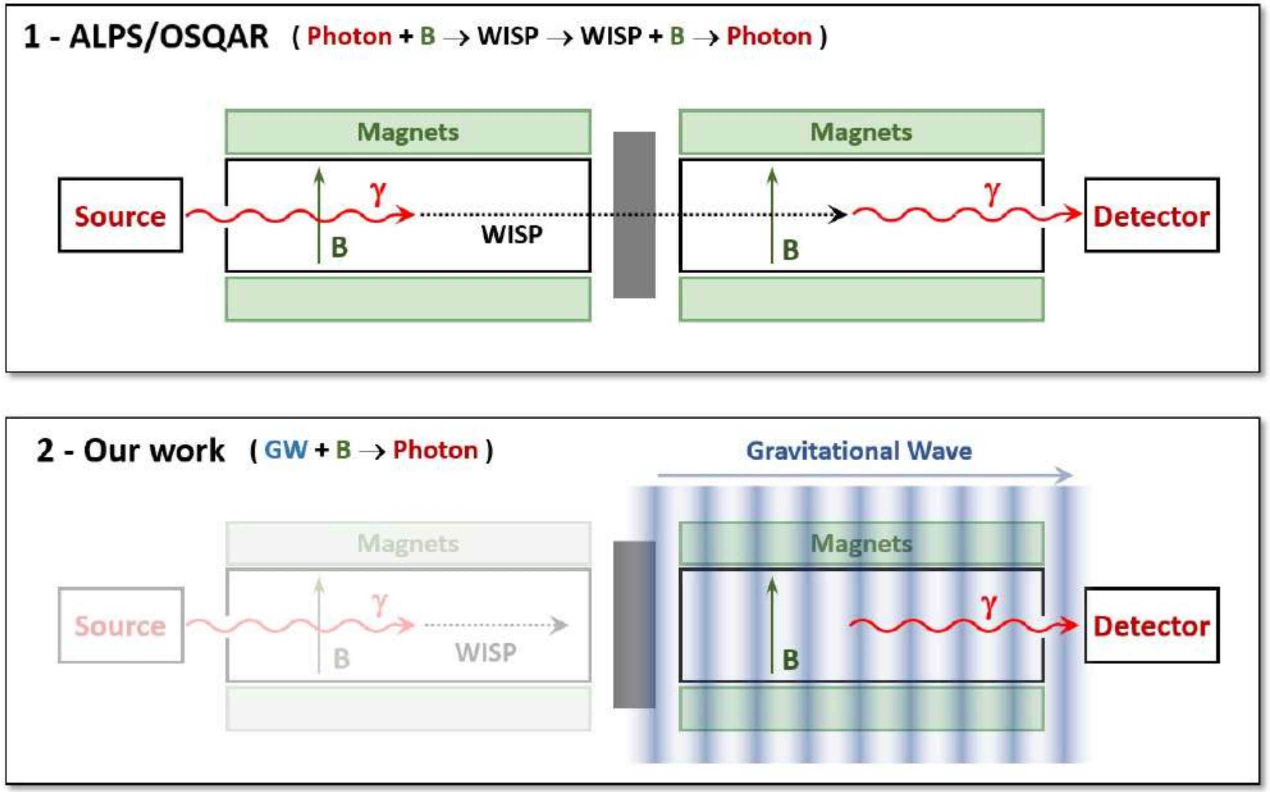
GWs upper limits: ALPS, OSQAR, CAST

Detectors

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

Suited sources?

- Requirements: stochastic, isotropic, stationary, and Gaussian gravitational-waves.



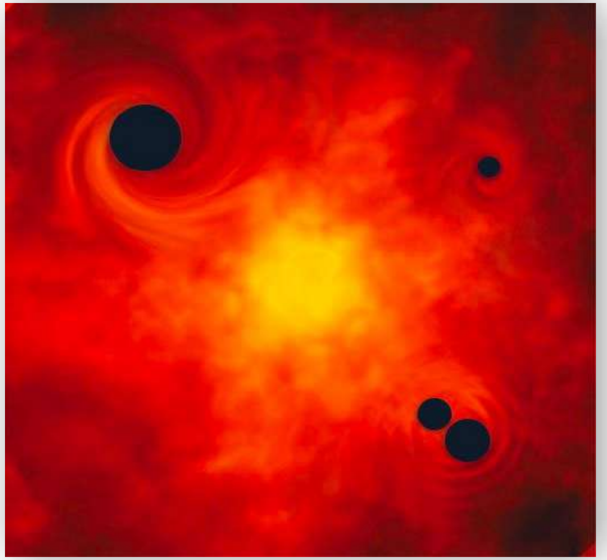
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

UHF GWS SOURCES

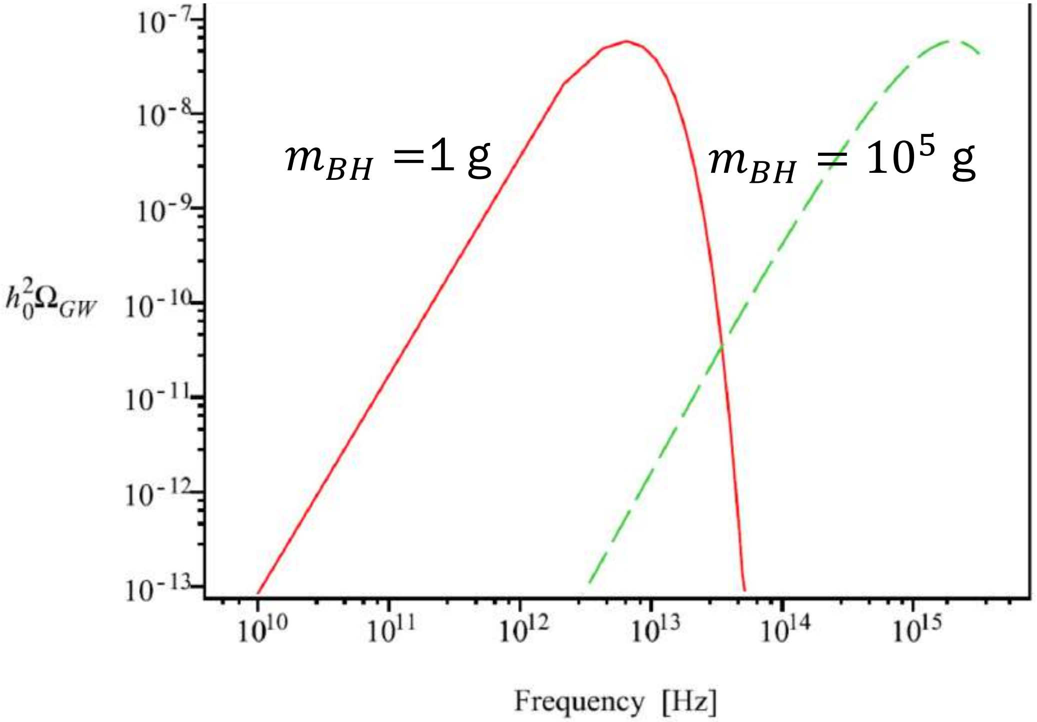
UHF GW sources: early universe

Primordial BH collisions and evaporations

- Cosmological energy density of the order of $h_0\Omega_{\rm GW}(f_{\rm peak}) \approx 10^{-7}$

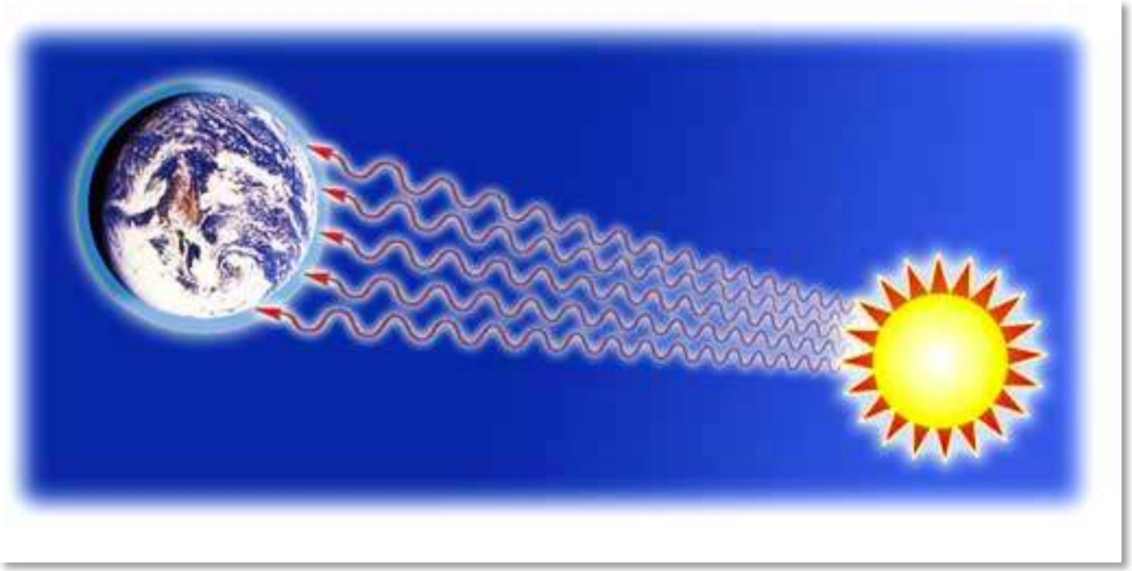


Phys.Rev.D 84 (2011) 024028



CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

UHF GW sources: thermal plasma in the sun

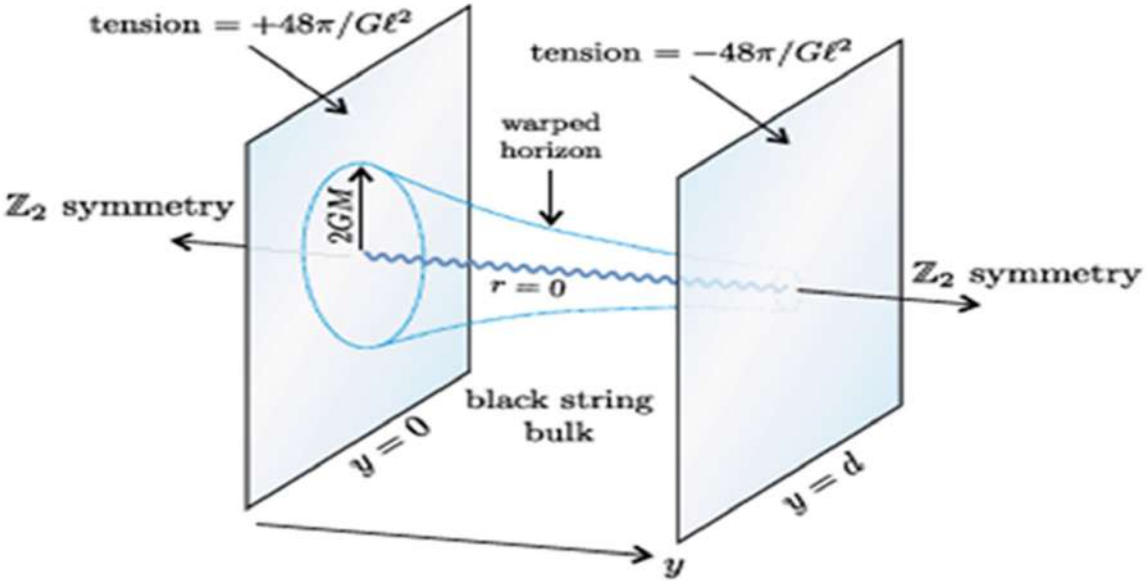


- Gravitational radiation emitted by Coulomb collision in plasma
- Hydrogen plasma in the solar core
- Collision frequency 10^{15} Hz
- Thermal collisions in the solar core produce about 10^{8} watts of gravitational radiation

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

S. Weinberg (ed.) Gravitation and Cosmology. Wiley, New York, p. 266 (1972)

UHF GW sources: BH-BH collisions in 5D gravity

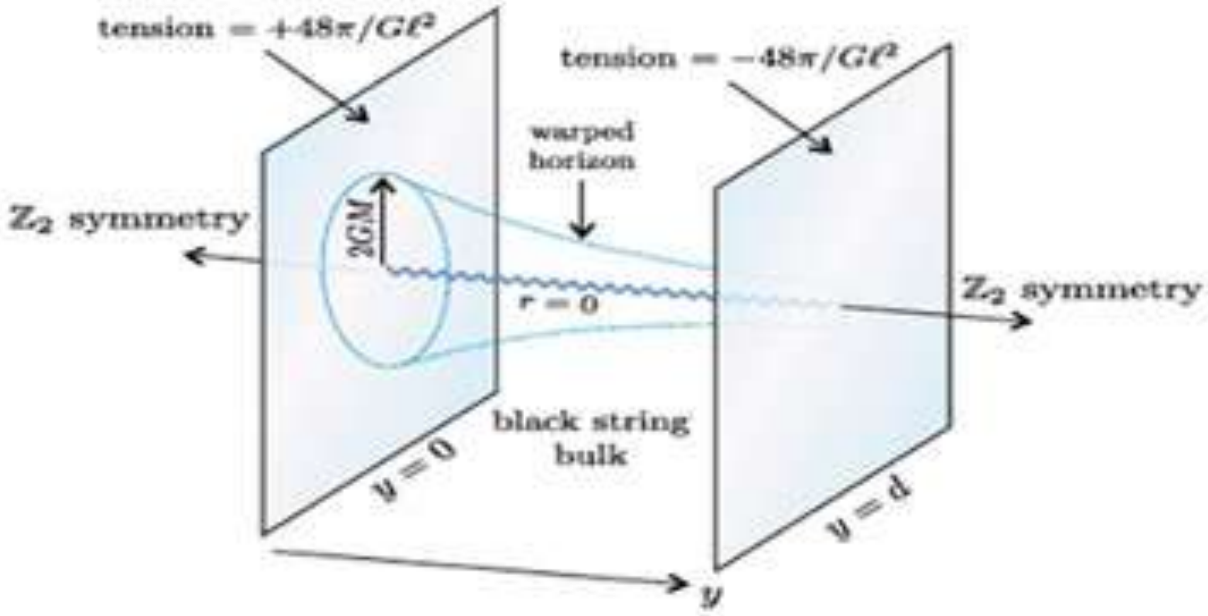


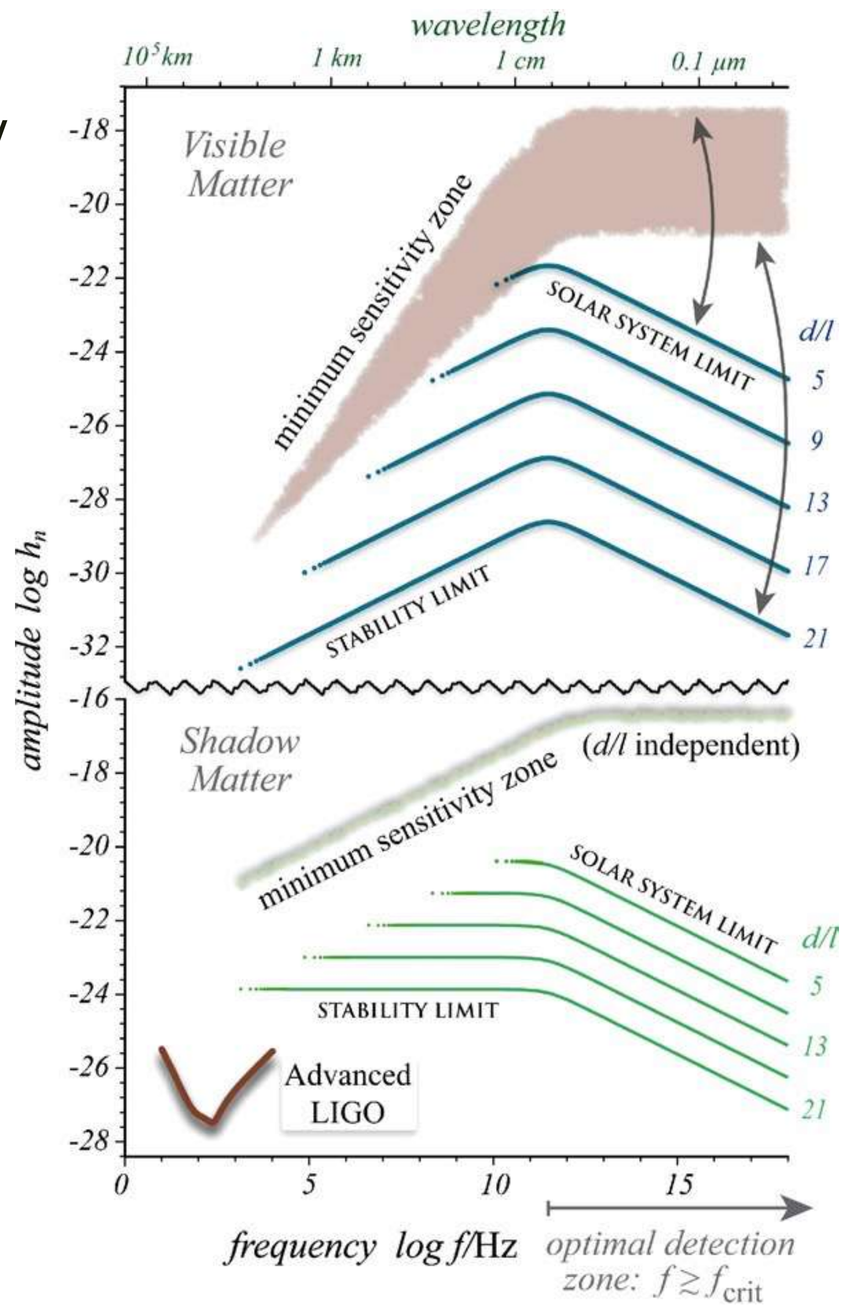
- Seahra and Clarkson have calculated the GW emission in 5-D gravity when stellar mass black holes fall into a black hole.
- The normal LF radiation from such a system is emitted plus an excitation of the brane separation itself

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Chris Clarkson and Sanjeev S Seahra 2007 *Class. Quantum Grav.* **24** F33

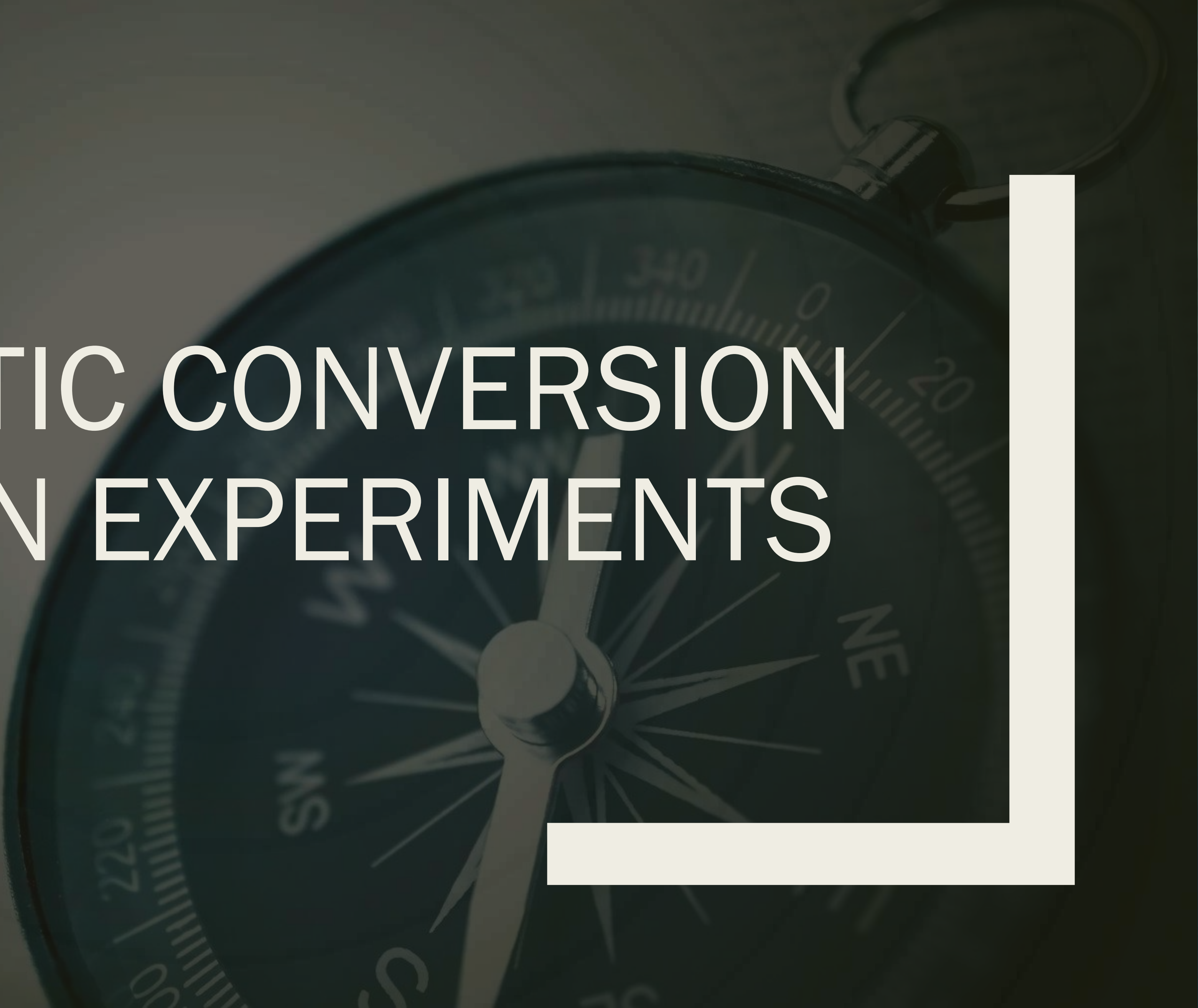
UHF GW sources: BH-BH collisions in 5D gravity





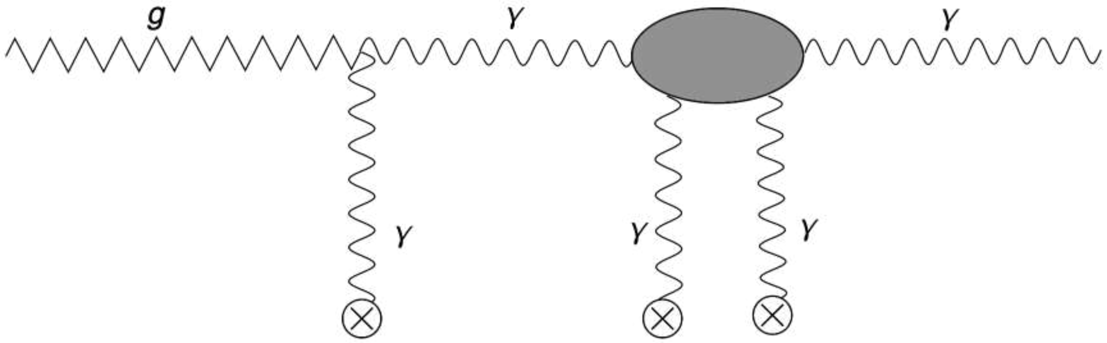
Chris Clarkson and Sanjeev S Seahra 2007 *Class. Quantum Grav.* **24** F33

MAGNETIC CONVERSION IN AXION EXPERIMENTS



GWs propagating in static magnetic fields

$$S = \int d^4x \sqrt{-g}\mathcal{L}$$



$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$

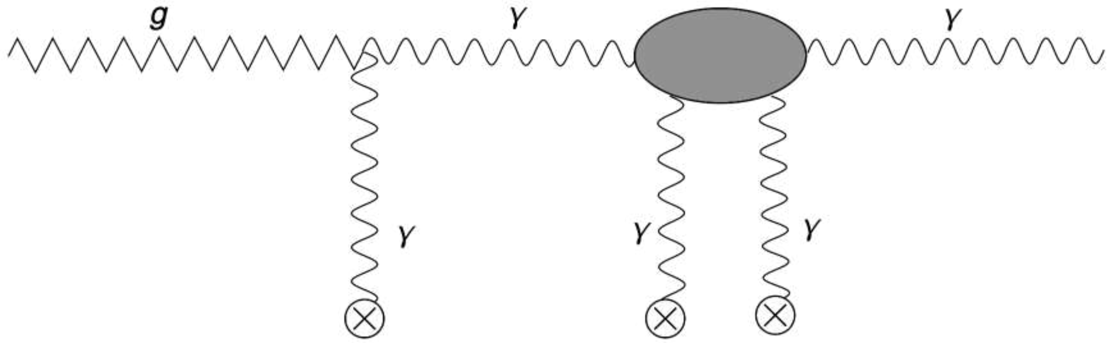
$$\mathcal{L}_{\rm gr} = \frac{1}{\kappa^2} R, \quad \mathcal{L}_{\rm em} = -\frac{1}{4} F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\int d^4x' A_\mu(x)\Pi^{\mu\nu}(x,x')A_\nu(x')$$

$$\begin{aligned} \nabla^2 A^0 &= 0, \\ \Box \boldsymbol{A}^i + \left(\int d^4x' \Pi^{ij}(x,x')\boldsymbol{A}_j(x')\right) + \partial^i\partial_\mu A^\mu &= \kappa\,\partial_\mu[h^{\mu\beta}\bar{F}^i_\beta - h^{i\beta}\bar{F}^\mu_\beta], \\ \Box h_{ij} &= -\kappa\,(B_i\bar{B}_j + \bar{B}_iB_j + \bar{B}_i\bar{B}_j), \end{aligned}$$

GWs propagating in static magnetic fields

$$S = \int d^4x \sqrt{-g}\mathcal{L}$$

$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$



$$(\omega + i\partial_z)\Psi(z,\omega,\hat{\boldsymbol{z}})\boldsymbol{I} + M(z,\omega)\Psi(z,\omega,\hat{\boldsymbol{z}}) = 0 \qquad \Psi(z,\omega,\hat{\boldsymbol{z}}) = (h_\times, h_+, A_x, A_y)^{\rm T}$$

$$M(z,\omega) = \begin{pmatrix} 0 & 0 & -iM^x_{g\gamma} & iM^y_{g\gamma} \\ 0 & 0 & iM^y_{g\gamma} & iM^x_{g\gamma} \\ iM^x_{g\gamma} & -iM^y_{g\gamma} & M_x & M_{\rm CF} \\ -iM^y_{g\gamma} & -iM^x_{g\gamma} & M^*_{\rm CF} & M_y \end{pmatrix}$$

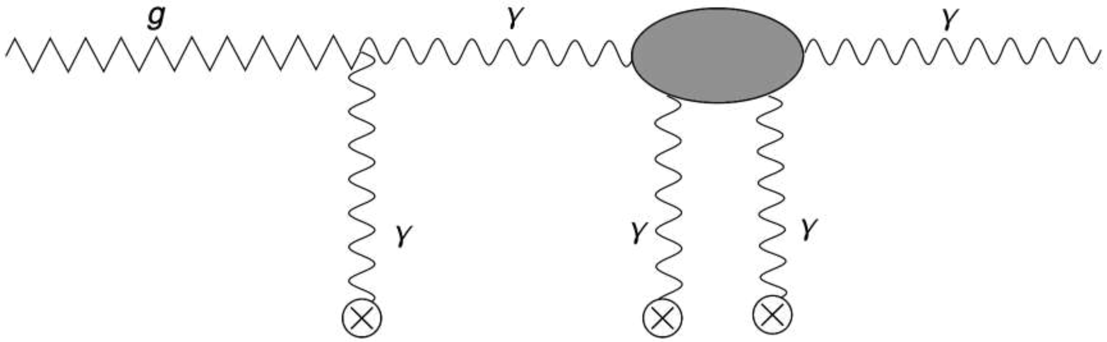
$$\begin{aligned} M^x_{g\gamma} &= \kappa\, k\bar{B}_x/(\omega+k) \\ M^y_{g\gamma} &= \kappa\, k\bar{B}_y/(\omega+k) \\ M_x &= -\Pi_{xx}/(\omega+k) \\ M_y &= -\Pi_{yy}/(\omega+k) \\ M_{\rm CF} &= -\Pi_{xy}/(\omega+k) \end{aligned}$$

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

GWs propagating in static magnetic fields

$$S = \int d^4x \sqrt{-g}\mathcal{L}$$

$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$



$$(\omega + i\partial_z)\Psi(z,\omega,\hat{\boldsymbol{z}})\boldsymbol{I} + M(z,\omega)\Psi(z,\omega,\hat{\boldsymbol{z}}) = 0 \qquad \Psi(z,\omega,\hat{\boldsymbol{z}}) = (h_\times, h_+, A_x, A_y)^{\rm T}$$

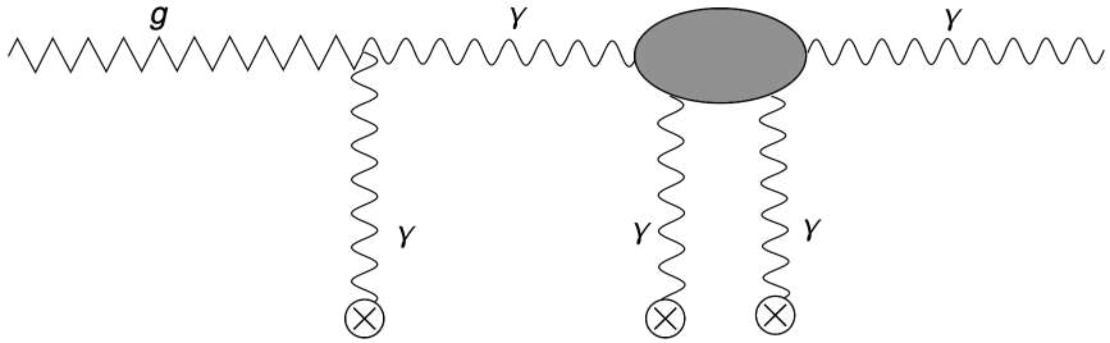
$$M(z,\omega) = \begin{pmatrix} 0 & 0 & -iM^x_{g\gamma} & iM^y_{g\gamma} \\ 0 & 0 & iM^y_{g\gamma} & iM^x_{g\gamma} \\ iM^x_{g\gamma} & -iM^y_{g\gamma} & M_x & M_{\rm CF} \\ -iM^y_{g\gamma} & -iM^x_{g\gamma} & M^*_{\rm CF} & M_y \end{pmatrix}$$

$$\begin{aligned} M^x_{g\gamma} &= \kappa\, k\bar{B}_x/(\omega + k) \\ M^y_{g\gamma} &= \kappa\, k\bar{B}_y/(\omega + k) \\ M_x &= -\Pi_{xx}/(\omega + k) \\ M_y &= -\Pi_{yy}/(\omega + k) \\ M_{\rm CF} &= -\Pi_{xy}/(\omega + k) \end{aligned}$$

GWs propagating in static magnetic fields

$$S = \int d^4x \sqrt{-g}\mathcal{L}$$

$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$



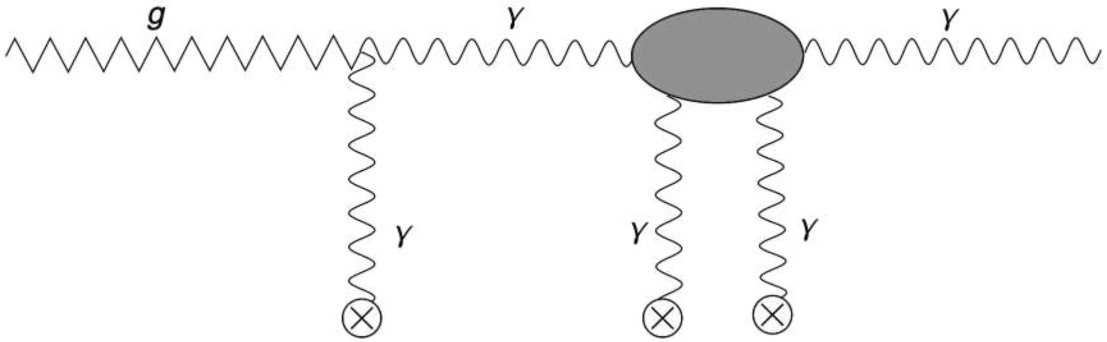
$$\begin{aligned}
h_\times(z,\omega,\hat{z}) &= \left[\cos(\Delta_x z) - i\frac{M_x \sin(\Delta_x z)}{2\Delta_x}\right] e^{i(\omega+M_x/2)z}\, h_\times(0,\omega,\hat{z}) + \frac{M^x_{g\gamma}\sin(\Delta_x z)}{\Delta_x} e^{i(\omega+M_x/2)z} A_x(0,\omega,\hat{z}),\\
h_+(z,\omega,\hat{z}) &= \left[\cos(\Delta_y z) - i\frac{M_y \sin(\Delta_y z)}{2\Delta_y}\right] e^{i(\omega+M_y/2)z}\, h_+(0,\omega,\hat{z}) - \frac{M^x_{g\gamma}\sin(\Delta_y z)}{\Delta_y} e^{i(\omega+M_y/2)z} A_y(0,\omega,\hat{z}),\\
A_x(z,\omega,\hat{z}) &= -\frac{M^x_{g\gamma}\sin(\Delta_x z)}{\Delta_x} e^{i(\omega+M_x/2)z}\, h_\times(0,\omega,\hat{z}) + \left[\cos(\Delta_x z) + i\frac{M_x \sin(\Delta_x z)}{2\Delta_x}\right] e^{i(\omega+M_x/2)z} A_x(0,\omega,\hat{z}),\\
A_y(z,\omega,\hat{z}) &= \frac{M^x_{g\gamma}\sin(\Delta_y z)}{\Delta_y} e^{i(\omega+M_y/2)z}\, h_+(0,\omega,\hat{z}) + \left[\cos(\Delta_y z) + i\frac{M_y \sin(\Delta_y z)}{2\Delta_y}\right] e^{i(\omega+M_y/2)z} A_y(0,\omega,\hat{z}).
\end{aligned}$$

$$\Delta_{x,y} \equiv \frac{\sqrt{M^2_{x,y} + 4(M^x_{g\gamma})^2}}{2}$$

GWs propagating in static magnetic fields

$$S = \int d^4x \sqrt{-g}\mathcal{L}$$

$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$



$$\begin{aligned}
h_\times(z,\omega,\hat{\boldsymbol{z}}) &= \left[\cos(\Delta_x z) - i\frac{M_x \sin(\Delta_x z)}{2\Delta_x}\right] e^{i(\omega+M_x/2)z}\, h_\times(0,\omega,\hat{\boldsymbol{z}}) + \frac{M^x_{g\gamma}\sin(\Delta_x z)}{\Delta_x} e^{i(\omega+M_x/2)z} A_x(0,\omega,\hat{\boldsymbol{z}}),\\
h_+(z,\omega,\hat{\boldsymbol{z}}) &= \left[\cos(\Delta_y z) - i\frac{M_y \sin(\Delta_y z)}{2\Delta_y}\right] e^{i(\omega+M_y/2)z}\, h_+(0,\omega,\hat{\boldsymbol{z}}) - \frac{M^x_{g\gamma}\sin(\Delta_y z)}{\Delta_y} e^{i(\omega+M_y/2)z} A_y(0,\omega,\hat{\boldsymbol{z}}),\\
A_x(z,\omega,\hat{\boldsymbol{z}}) &= -\frac{M^x_{g\gamma}\sin(\Delta_x z)}{\Delta_x} e^{i(\omega+M_x/2)z}\, h_\times(0,\omega,\hat{\boldsymbol{z}}) + \left[\cos(\Delta_x z) + i\frac{M_x \sin(\Delta_x z)}{2\Delta_x}\right] e^{i(\omega+M_x/2)z} A_x(0,\omega,\hat{\boldsymbol{z}}),\\
A_y(z,\omega,\hat{\boldsymbol{z}}) &= \frac{M^x_{g\gamma}\sin(\Delta_y z)}{\Delta_y} e^{i(\omega+M_y/2)z}\, h_+(0,\omega,\hat{\boldsymbol{z}}) + \left[\cos(\Delta_y z) + i\frac{M_y \sin(\Delta_y z)}{2\Delta_y}\right] e^{i(\omega+M_y/2)z} A_y(0,\omega,\hat{\boldsymbol{z}})
\end{aligned}$$

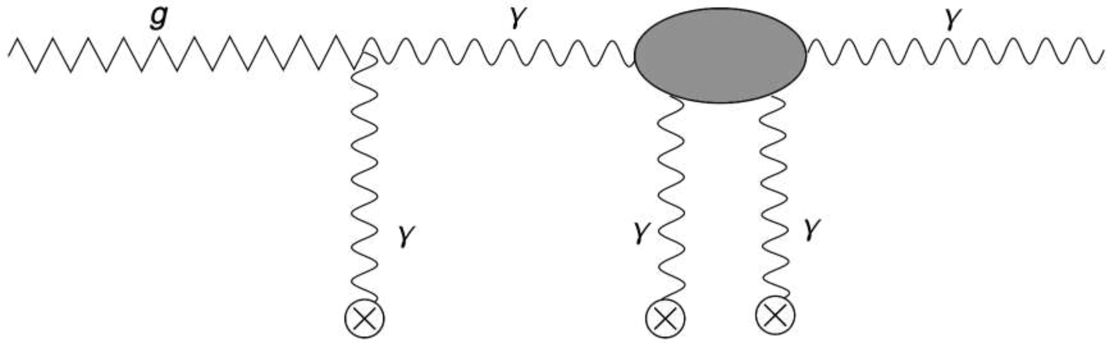
$$\Delta_{x,y} \equiv \frac{\sqrt{M^2_{x,y} + 4(M^x_{g\gamma})^2}}{2}$$

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

GWs propagating in static magnetic fields

$$S = \int d^4x\sqrt{-g}\mathcal{L}$$

$$\mathcal{L} = \mathcal{L}_{\rm gr} + \mathcal{L}_{\rm em}$$



$$A_x(z,\omega,\hat{\boldsymbol{z}}) = -\frac{M^x_{g\gamma}\sin(\Delta_x z)}{\kappa\Delta_x}e^{i(\omega+M_x/2)z}\,\tilde{h}_\times(0,\omega,\hat{\boldsymbol{z}})$$

$$A_y(z,\omega,\hat{\boldsymbol{z}}) = \frac{M^x_{g\gamma}\sin(\Delta_y z)}{\kappa\Delta_y}e^{i(\omega+M_y/2)z}\,\tilde{h}_+(0,\omega,\hat{\boldsymbol{z}}).$$

CARDI
UNIVERS
PRIFYSG
CAERDY

GWs propagating in static magnetic fields

- EMWs flux: $$\Phi_\gamma(z,t) \equiv \langle |E_x(z,t)|^2\rangle + \langle |E_y(z,t)|^2\rangle$$
- Stochastic GWs tensor $$\tilde{h}_{ij}(0,t) = \sum_{\lambda=\times,+} \int_{-\infty}^{+\infty} \frac{d\omega}{2\pi} \int_{S^2} d^2\hat{\boldsymbol{n}}\, \tilde{h}_\lambda(0,\omega,\hat{\boldsymbol{n}}) e^\lambda_{ij}(\hat{\boldsymbol{n}})\, e^{-i\omega t}$$
- Average value: $$\langle \tilde{h}_{ij}(0,t)\tilde{h}^{ij}(0,t)\rangle \equiv 2\int_0^{+\infty} d(\log\omega) h_c^2(0,\omega),$$

Converted EMWs stochastic flux

$$\Phi_\gamma^{\text{graph}}(z,\omega_f;t) \simeq \int_{\omega_i}^{\omega_f} \frac{B^2\, z^2\, h_c^2(0,\omega)\,\omega}{4} d\omega$$

Measured EMWs flux from the CCD

$$\Phi_\gamma^{\text{CCD}}(z,\omega_f;t) = \int_{\omega_i}^{\omega_f} \frac{1}{A(z)} \frac{N(\omega,t)\,\omega}{\epsilon_\gamma(\omega)}\, d\omega$$

$$N(\omega,t) = N_{\text{exp}}/\Delta\omega$$

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

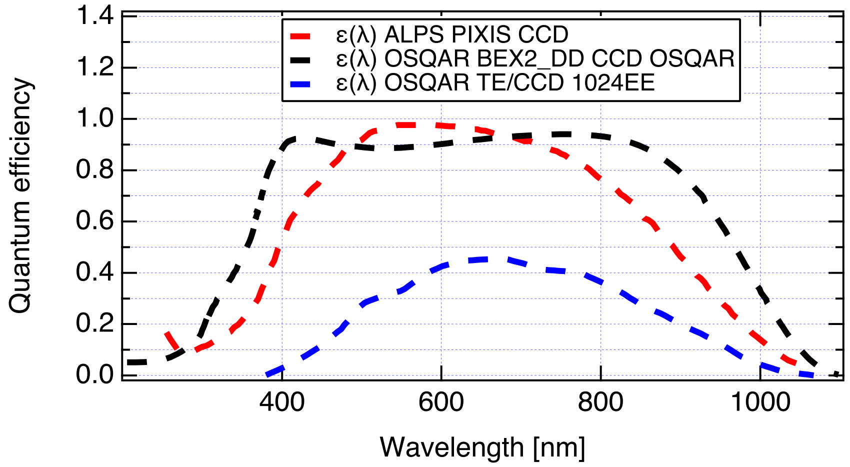
PRIFYSGOL CAERDYDD

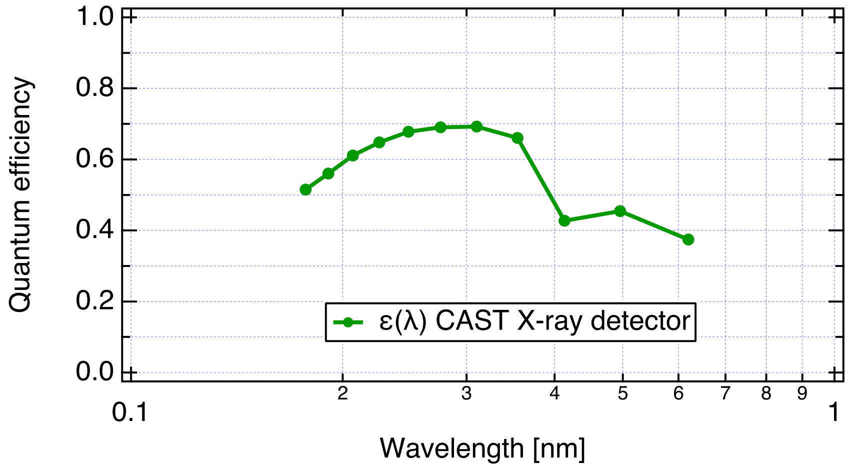
Parameters necessary to compute the characteristic amplitude

$$h_c^{\min}(0,\omega) \simeq \sqrt{\frac{4\,N_{\rm exp}}{A\,B^2\,L^2\,\epsilon_\gamma(\omega)\,\Delta\omega}} \simeq 1.6\times10^{-16}\sqrt{\left(\frac{N_{\rm exp}}{1\ {\rm Hz}}\right)\left(\frac{1\ {\rm m}^2}{A}\right)\left(\frac{1\ {\rm T}}{B}\right)^2\left(\frac{1\ {\rm m}}{L}\right)^2\left(\frac{1\ {\rm Hz}}{\Delta f}\right)\left(\frac{1}{\epsilon_\gamma(\omega)}\right)}$$

- N_{exp} - detected number of photons per second,
- A - cross-section of the detector,
- B - magnetic field amplitude,
- L - distance extension of the magnetic field,
- $\epsilon_\gamma(\omega)$ - quantum efficiency of the detector,
- Δf - operation frequency of the CCD.

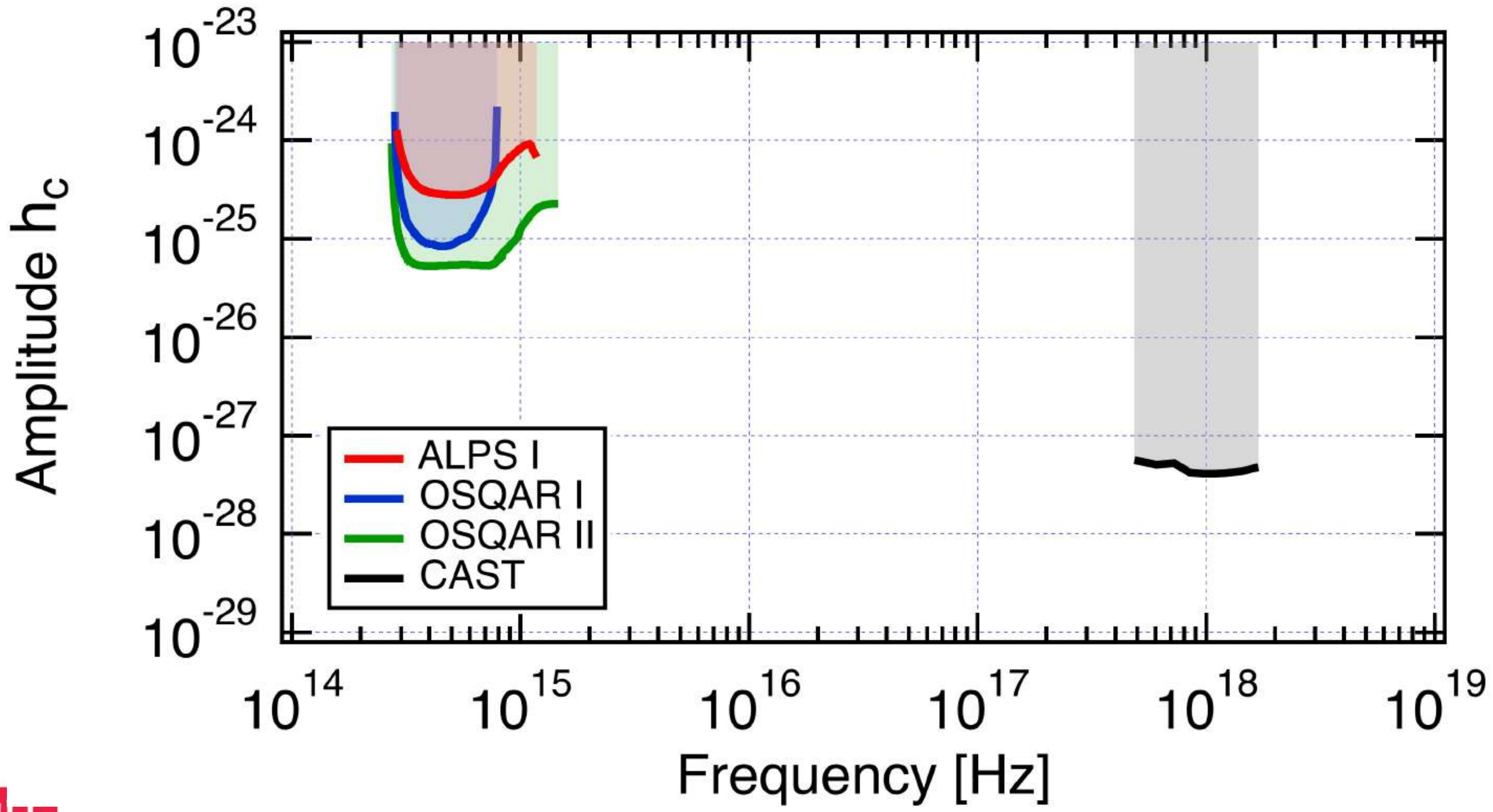
	$\epsilon_\gamma(\omega)$	$N_{\rm exp}$ (mHz)	A ($\rm m^2$)	B (T)	L (m)	Δf (Hz)
ALPS I	see Fig 2	0.61	0.5×10^{-3}	5	9	9×10^{14}
OSQAR I	see Fig 2	1.76	0.5×10^{-3}	9	14.3	5×10^{14}
OSQAR II	see Fig 2	1.14	0.5×10^{-3}	9	14.3	1×10^{15}
CAST	see Fig 2	0.15	2.9×10^{-3}	9	9.26	1×10^{18}





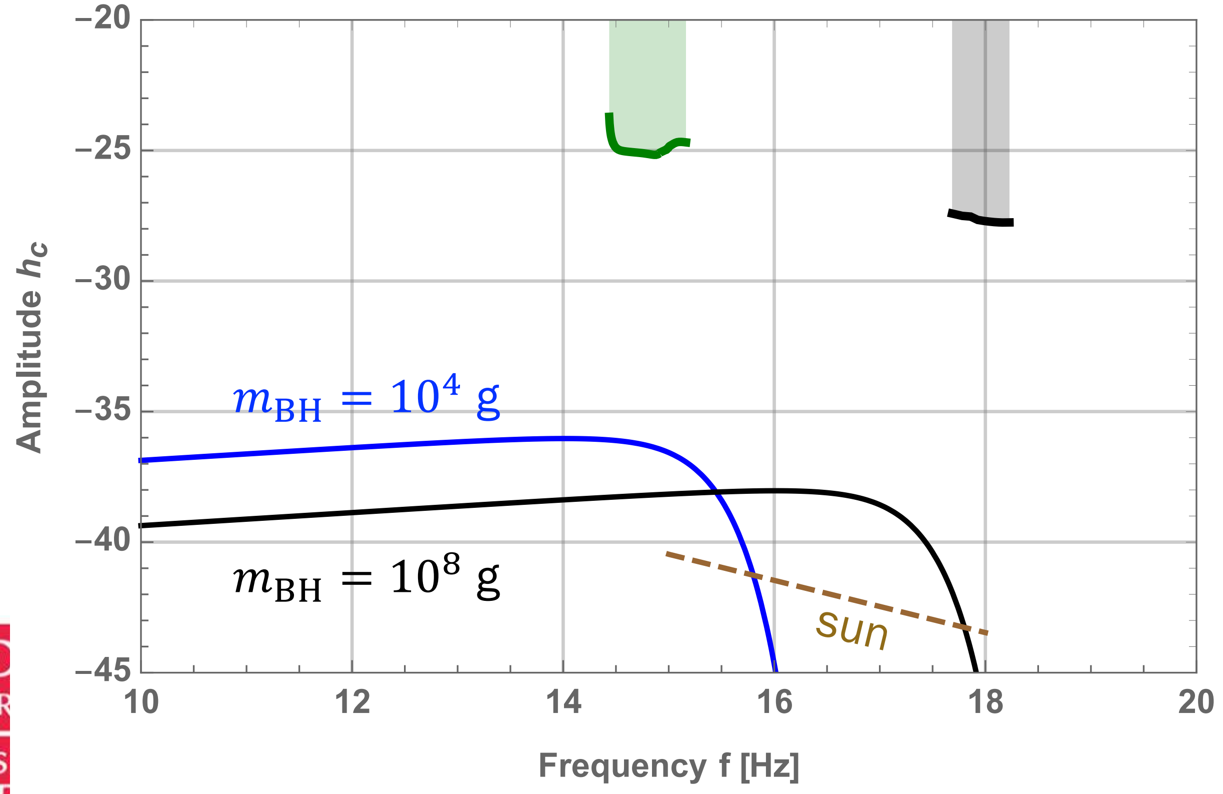
PRIFYSGOL CAERDYDD

UHF GW characteristic amplitude upper limits

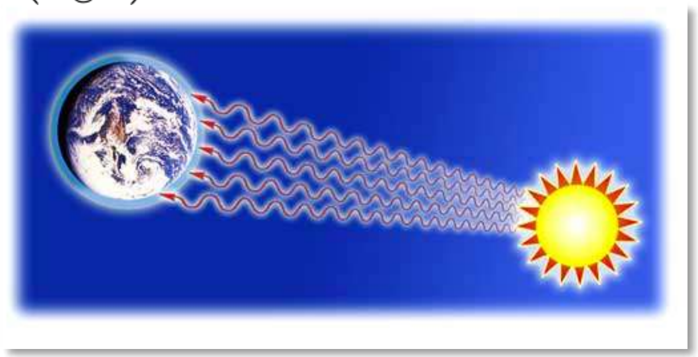


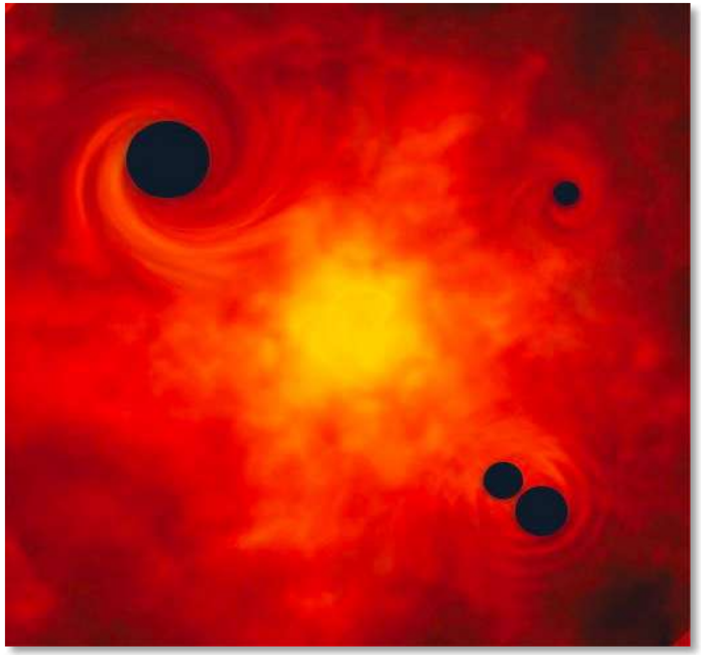
Primordial black hole evaporation and upper limits

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

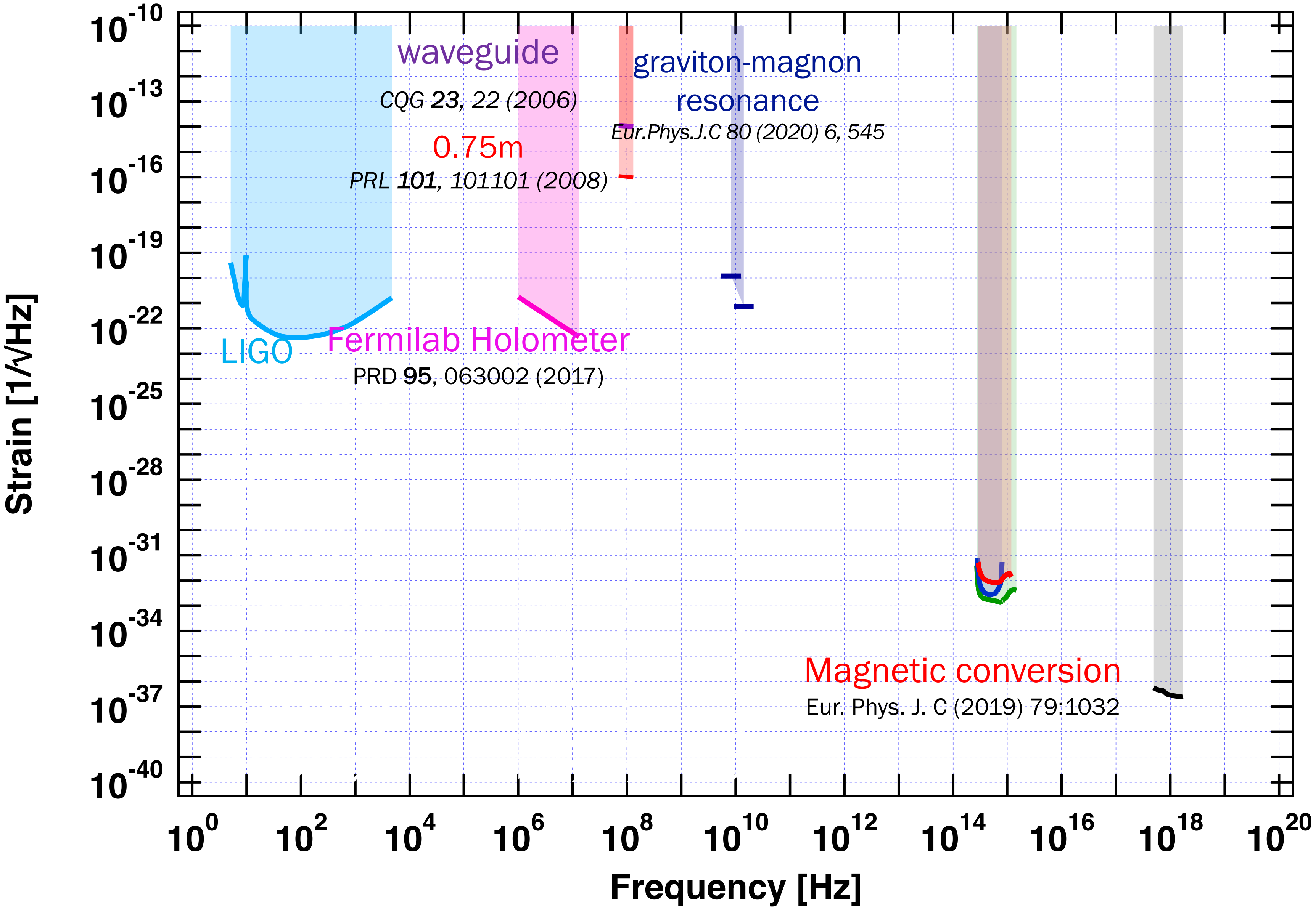


$$\frac{d\rho_\gamma^{\rm Sun}}{d(\log\omega)} \approx 5.7\times10^{-62}\ {\rm GeV}^4\ @\ {\rm Earth}$$





STRAIN UPPER LIMITS



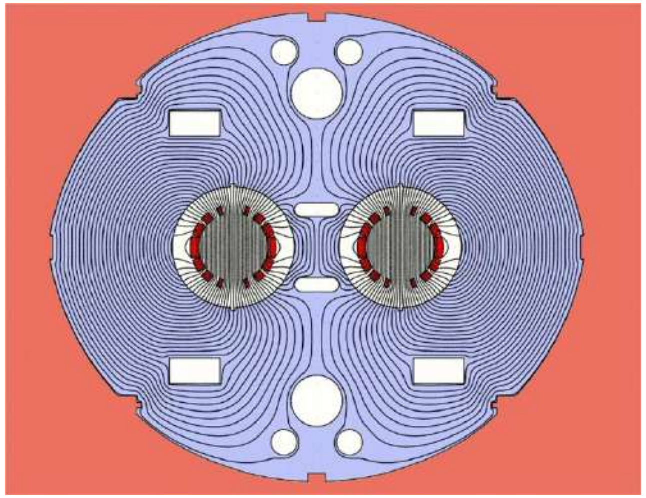
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

WHERE TO NEXT?

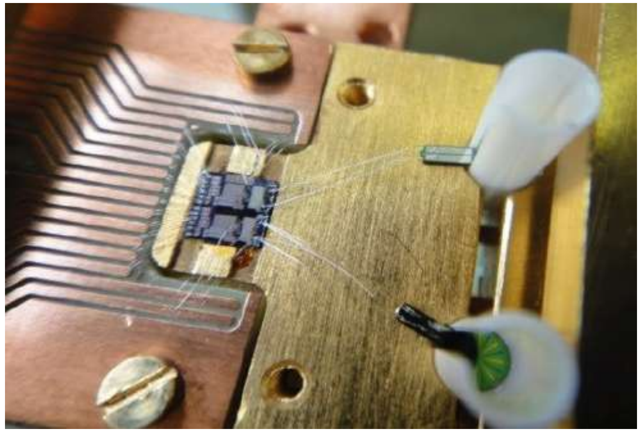
Graviton to photon conversion and synergies with next generation axion search experiments

$$h_c^{\min}(0,\omega) \simeq \sqrt{\frac{4\,N_{\rm exp}}{A\,B^2\,L^2\,\epsilon_\gamma(\omega)\,\Delta\omega}} \simeq 1.6\times10^{-16}\sqrt{\left(\frac{N_{\rm exp}}{1\ {\rm Hz}}\right)\left(\frac{1\ {\rm m}^2}{A}\right)\left(\frac{1\ {\rm T}}{B}\right)^2\left(\frac{1\ {\rm m}}{L}\right)^2\left(\frac{1\ {\rm Hz}}{\Delta f}\right)\left(\frac{1}{\epsilon_\gamma(\omega)}\right)}$$

- N_{exp} - detected number of photons per second
- A - cross-section of the detector
- B - magnetic field amplitude
- L - distance extension of the magnetic field
- $\epsilon_\gamma(\omega)$ - quantum efficiency of the detector
- Δf - operation frequency of the CCD

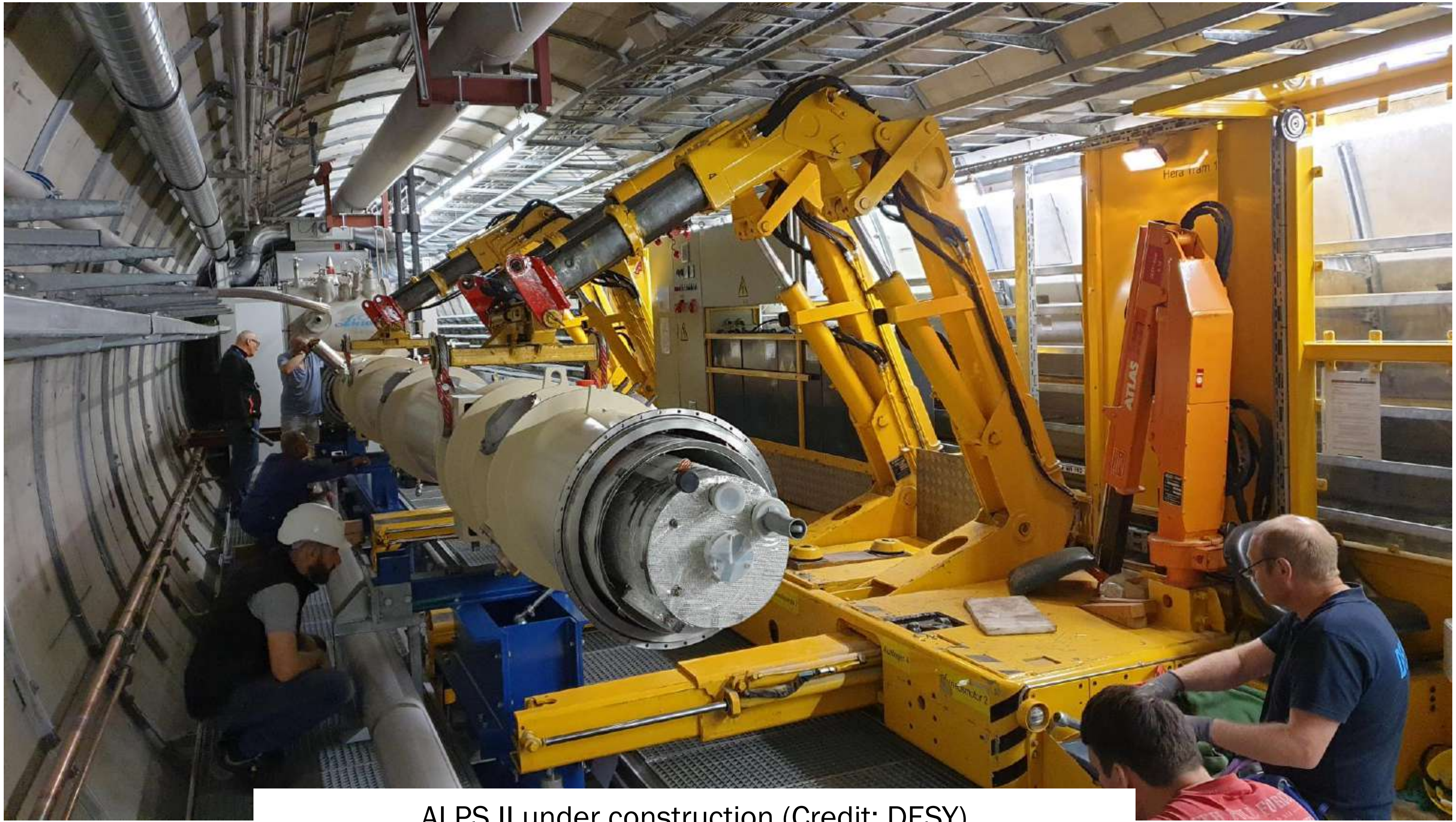


TES



CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

ALPSII: Magnets installation

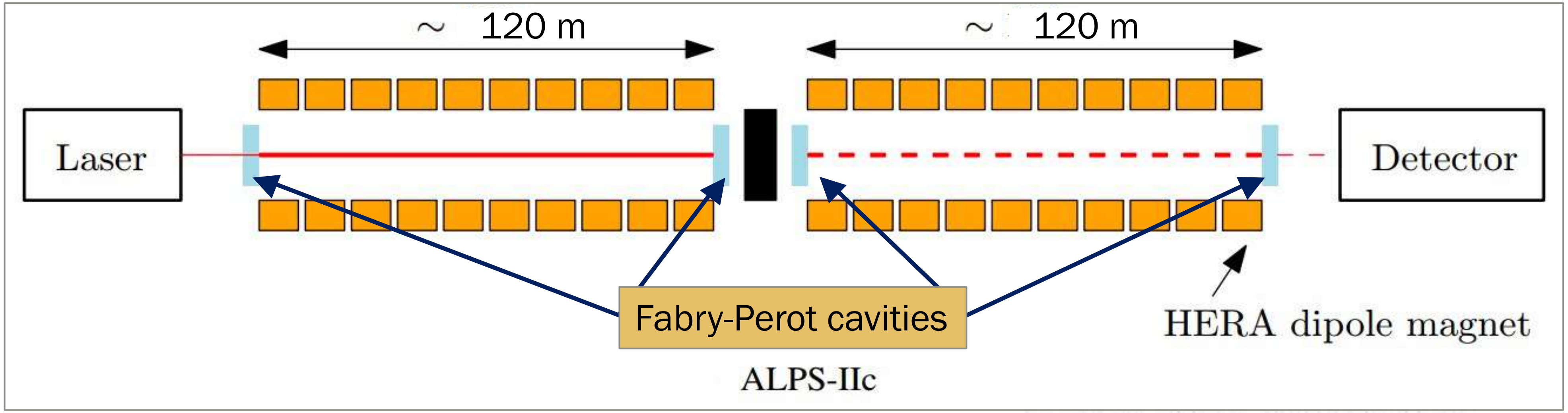


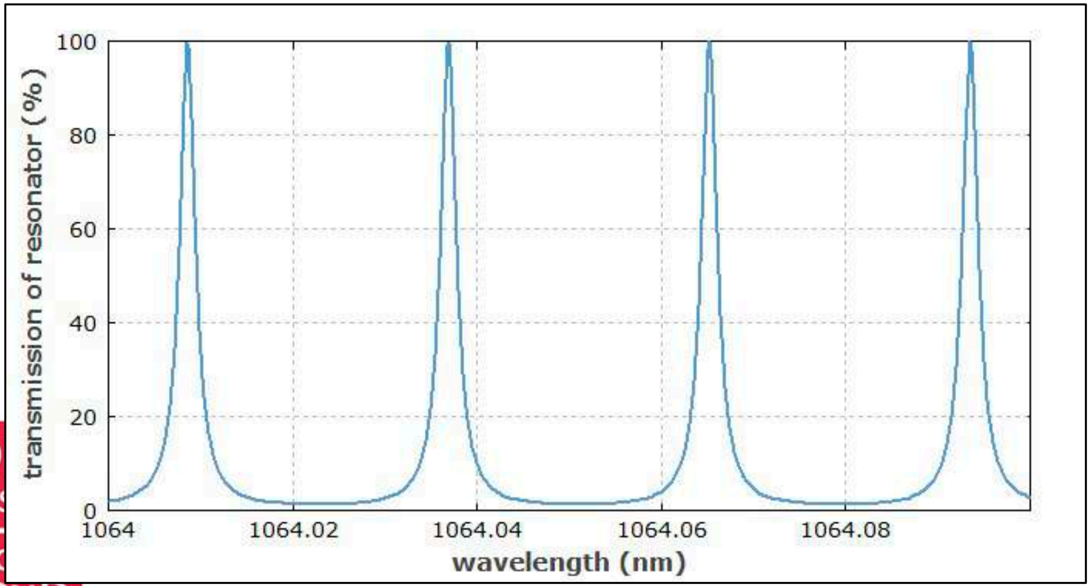
ALPS II under construction (Credit: DESY)

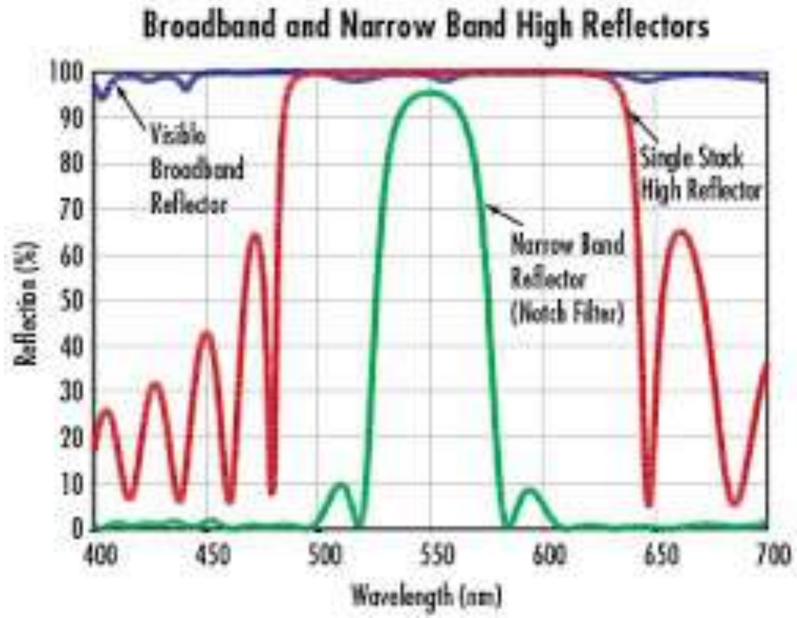
ALPS II

ALPS II under construction as of October 2020 (Credit: DESY)

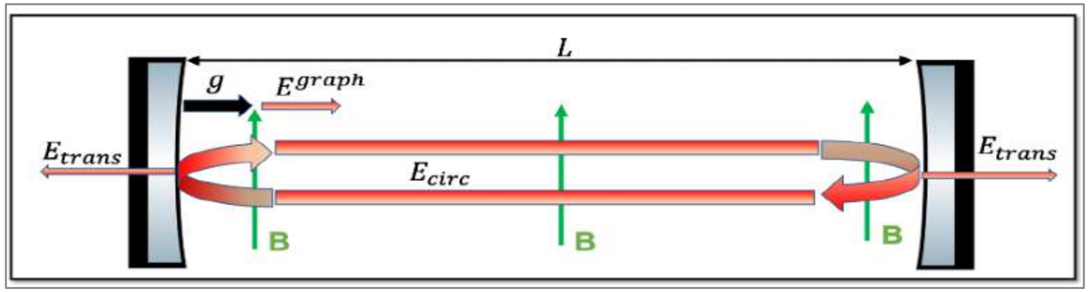
ALPS II: Fabry-Perot cavities

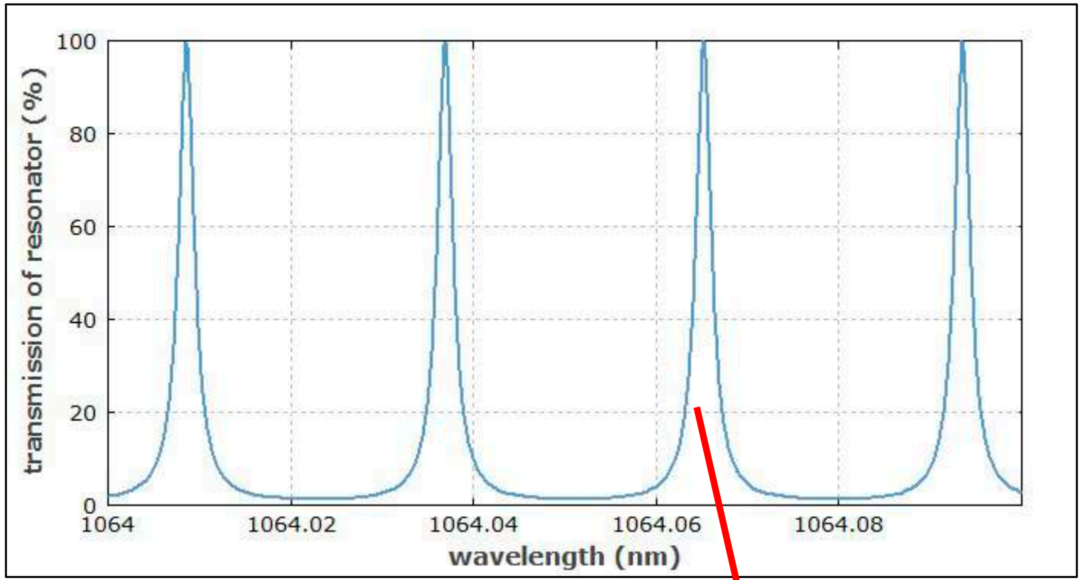






Graviton-to-photon in the conversion Fabry-Perot cavity





$$\vec{E}^{\rm circ}_{x,y}(z,t) = \vec{E}^{\rm graph}_{x,y}(z,t)\left(1 + Re^{-i2\phi(\omega,L)} + \left(Re^{-i2\phi(\omega,L)}\right)^2 + \cdots\right)$$

$$= \vec{E}^{\rm graph}_{x,y}(z,t)\sum_{n=0}^{\infty}\left(Re^{-i2\phi(\omega,L)}\right)^n$$

$$= \vec{E}^{\rm graph}_{x,y}(z,t)\frac{1}{1 - Re^{-i2\phi(\omega,L)}}$$

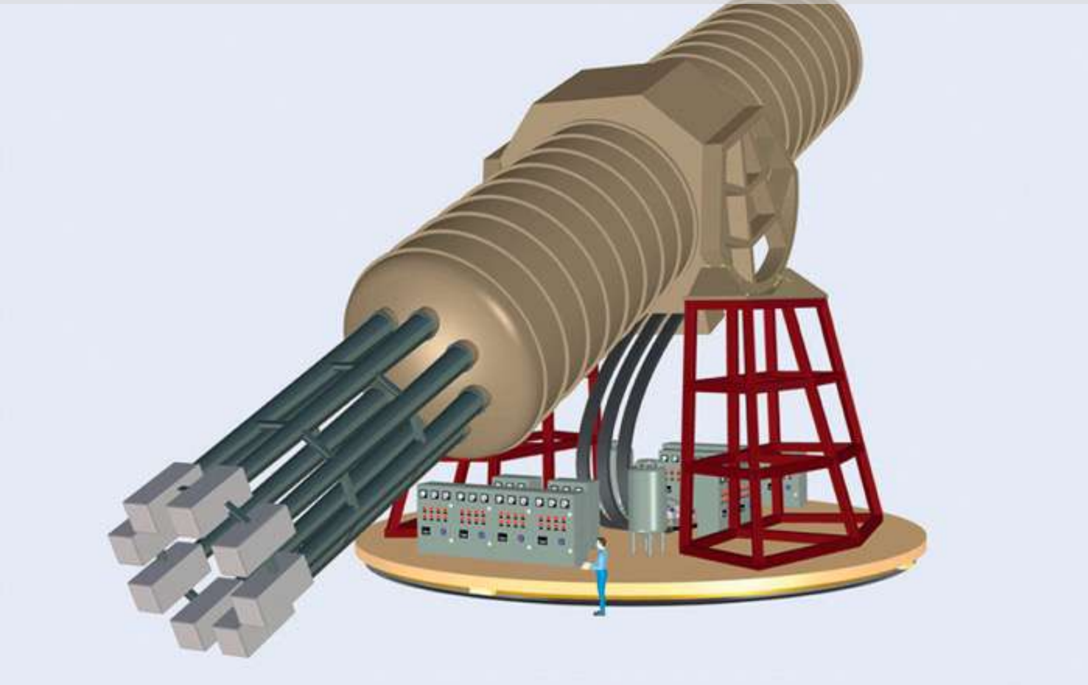
$$\Phi^{\rm trans}_{\gamma}(L,\omega_f;t) = \int_{\omega_i}^{\omega_f}\frac{B_x^2L^2h_c(0,\omega)^2}{4}\frac{1-R}{(1-R)^2 + 4R\sin^2\left[\phi(\omega,L)\right]}\,\omega\, d\omega.$$

$$\frac{B_x^2L^2h_c(0,\omega)^2}{4}\frac{\mathcal{F}}{\pi}\omega \qquad \text{for} \qquad \phi(\omega,L_R) = n\pi$$

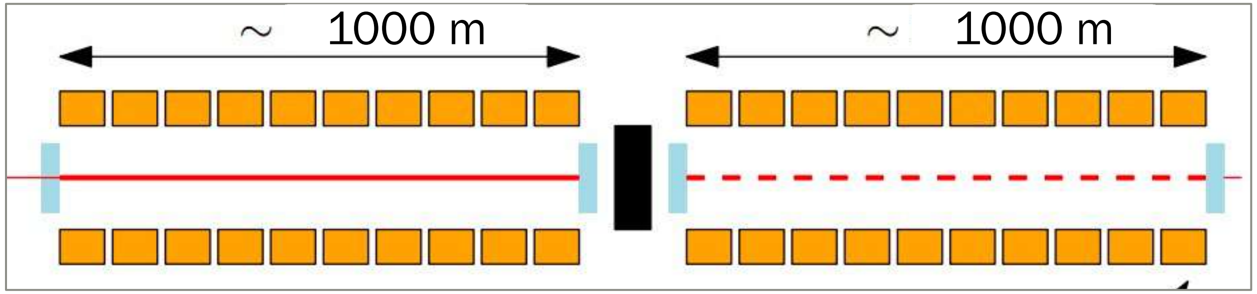
$$h_c^{\rm min}(0,\omega^*) \simeq 2.8\times10^{-16}\sqrt{\left(\frac{1}{\mathcal{F}}\right)\left(\frac{N_{\rm dark}}{1\ {\rm Hz}}\right)\left(\frac{1\ {\rm m}^2}{A}\right)\left(\frac{1\ {\rm T}}{B}\right)^2\left(\frac{1\ {\rm m}}{L}\right)^2\left(\frac{1\ {\rm Hz}}{\Delta f}\right)\left(\frac{1}{\epsilon_\gamma(\omega)}\right)}$$

Future laboratory axion experiments: JURA, IAXO.

IAXO (*Armengaud et al. JINST 9 T05002 (2014)*)



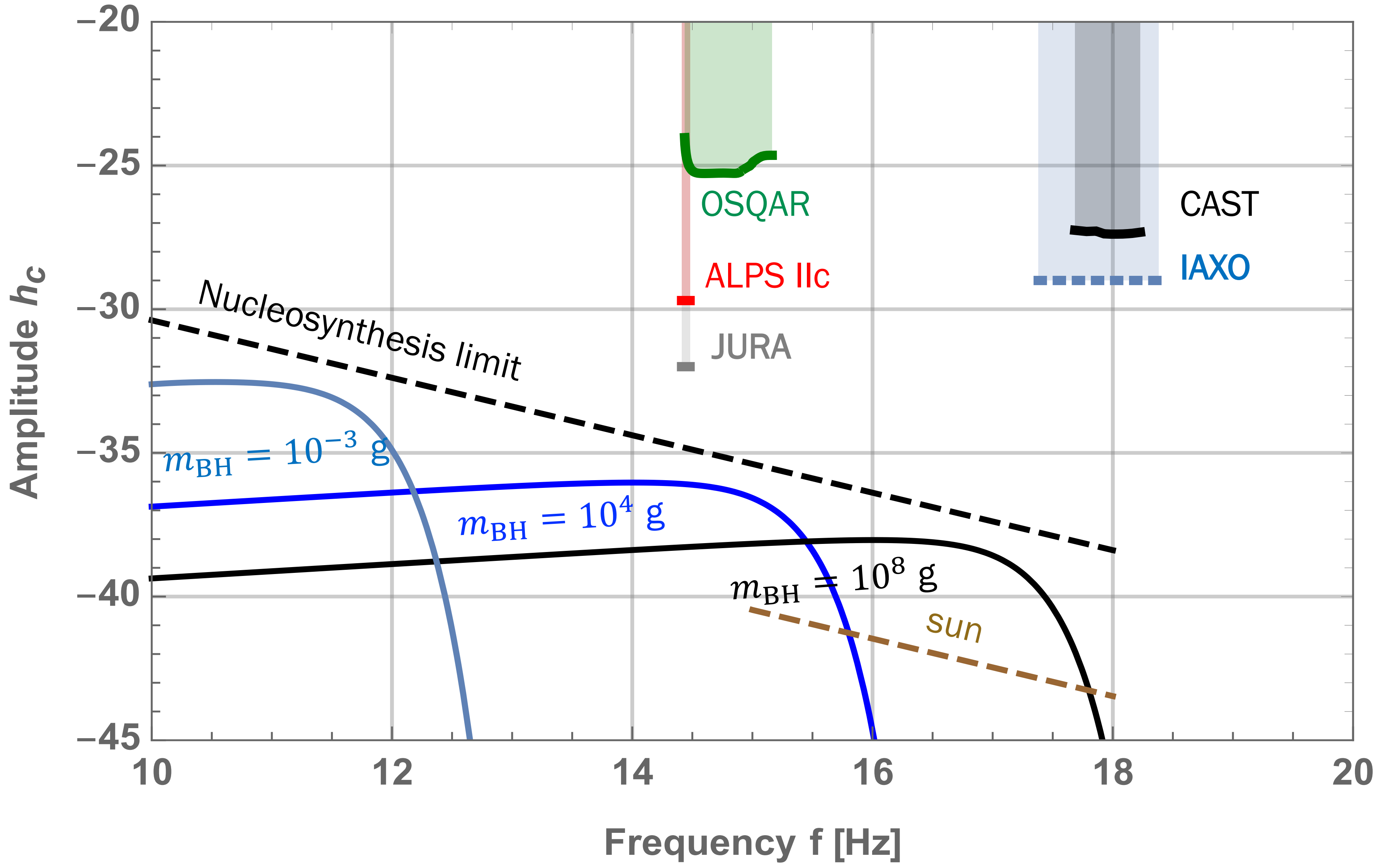
JURA



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

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

Prospects

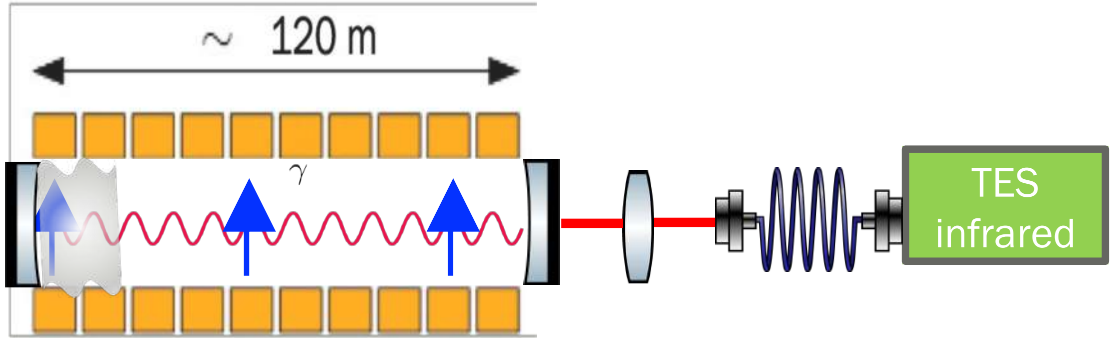


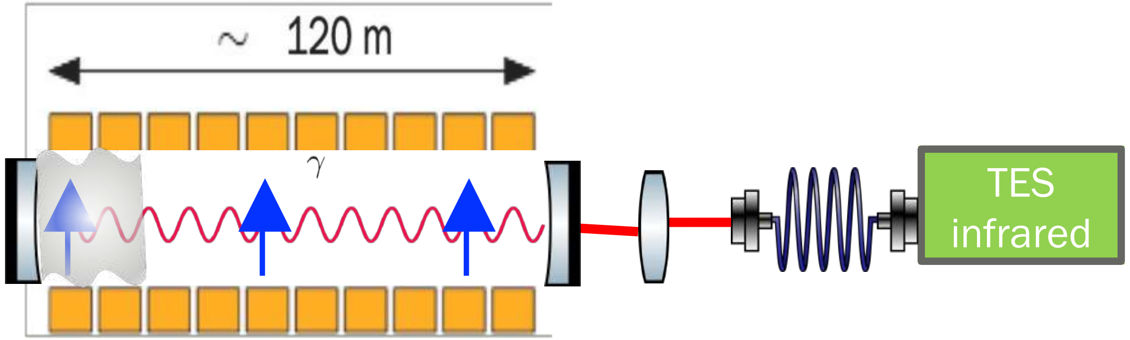
Work in collaboration with: Mike Cruise, Damian Ejlli, Giampaolo Pisano, and Hartmut Grote

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

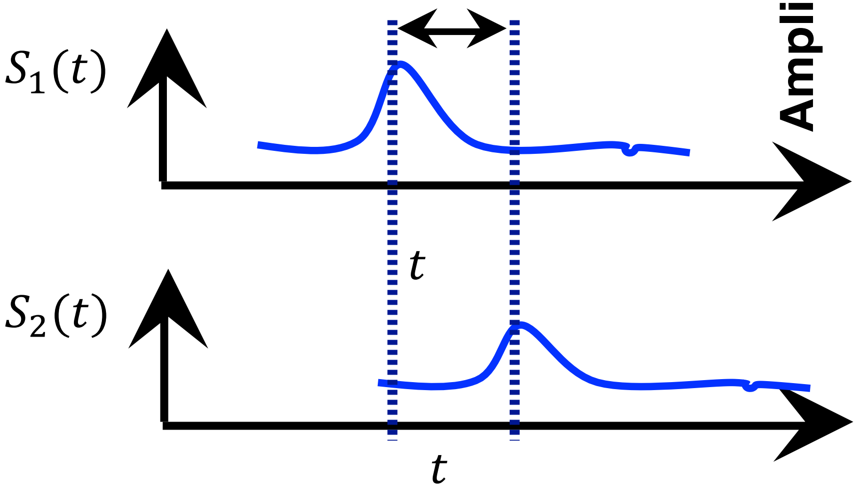

UPGRADES?

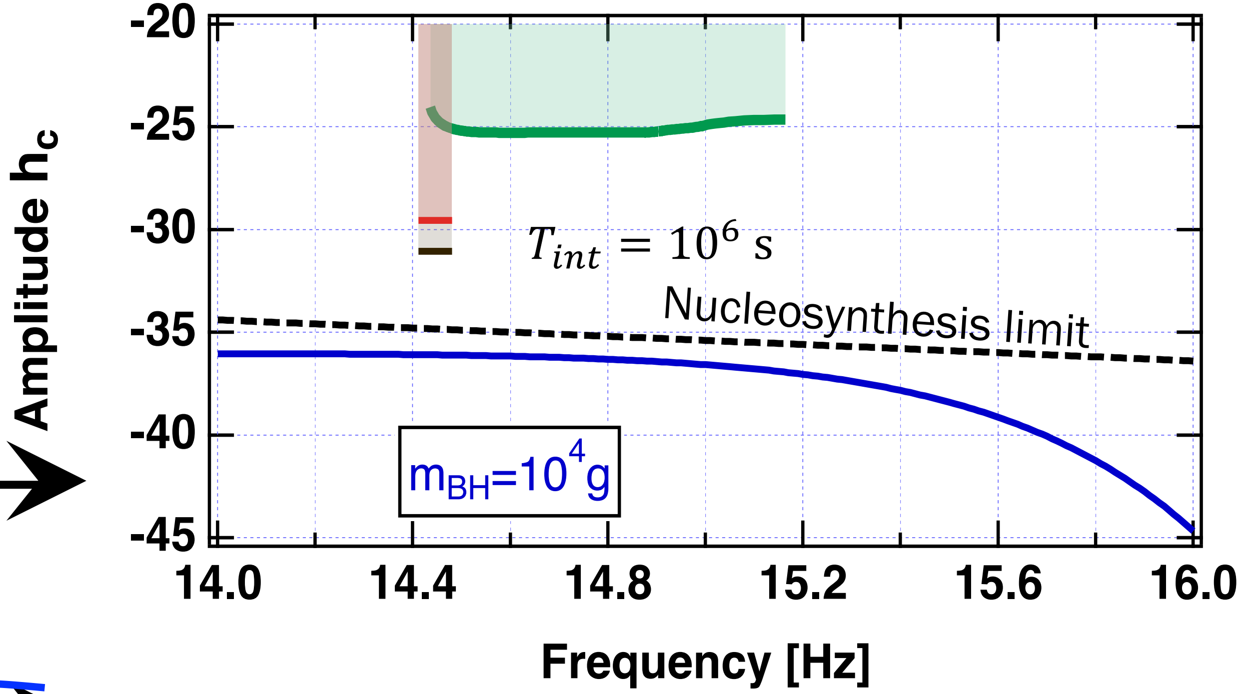
ALPS II: modifications



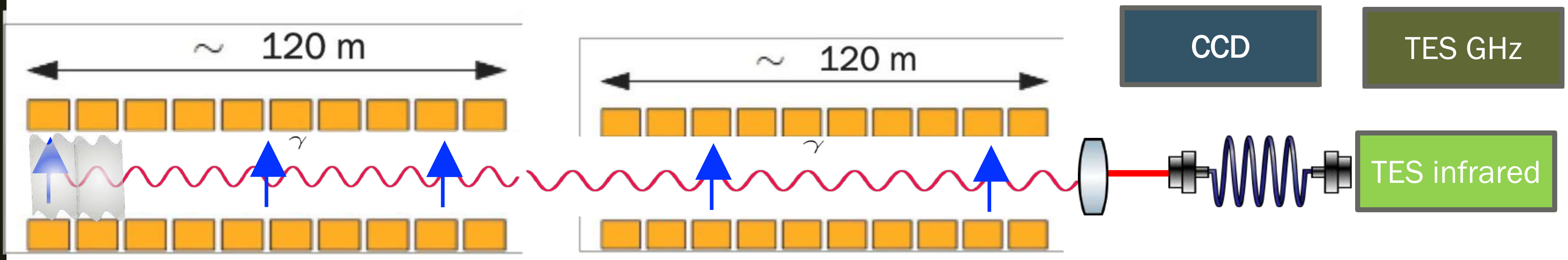


- Cross correlation
- Reduction background noise
- Possible identification of GW's transients

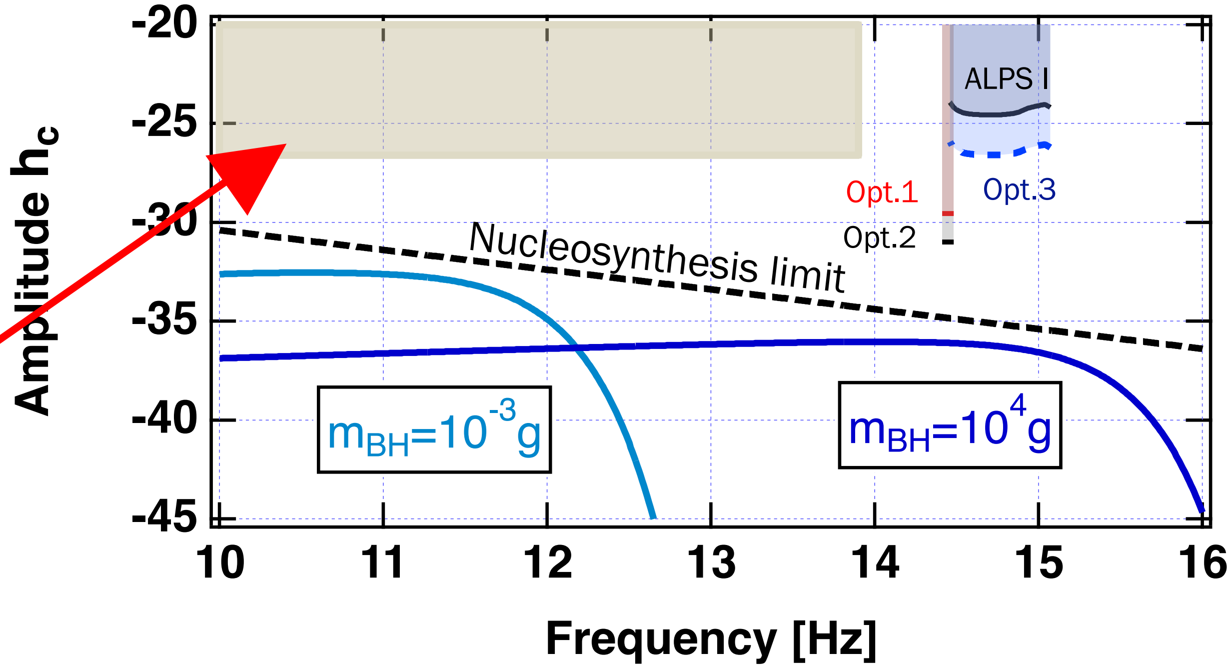




ALPS II without FP cavities

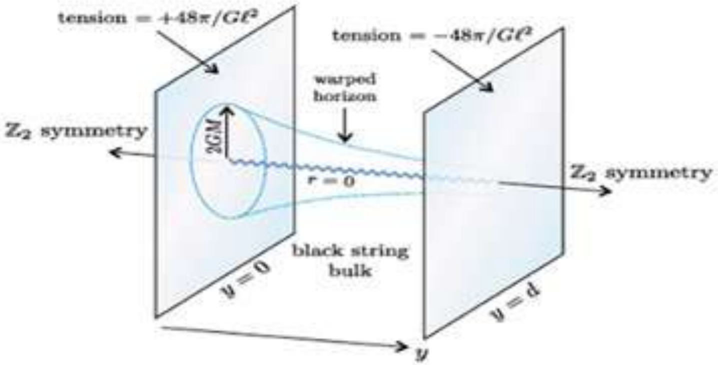


- Double length 2x106 m of the magnetic field.
- Possibility to investigate new frequency regions
- Interesting region in the GHz!



CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

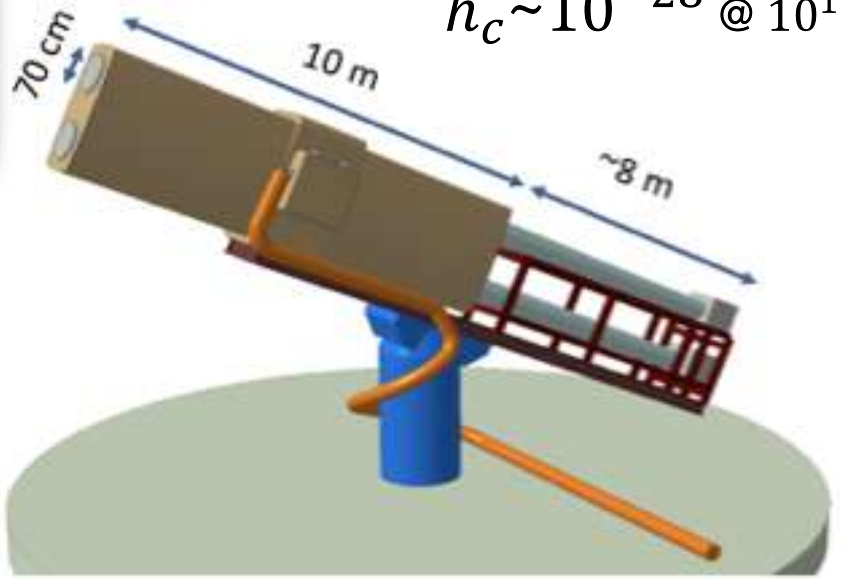
Baby IAXO, IAXO

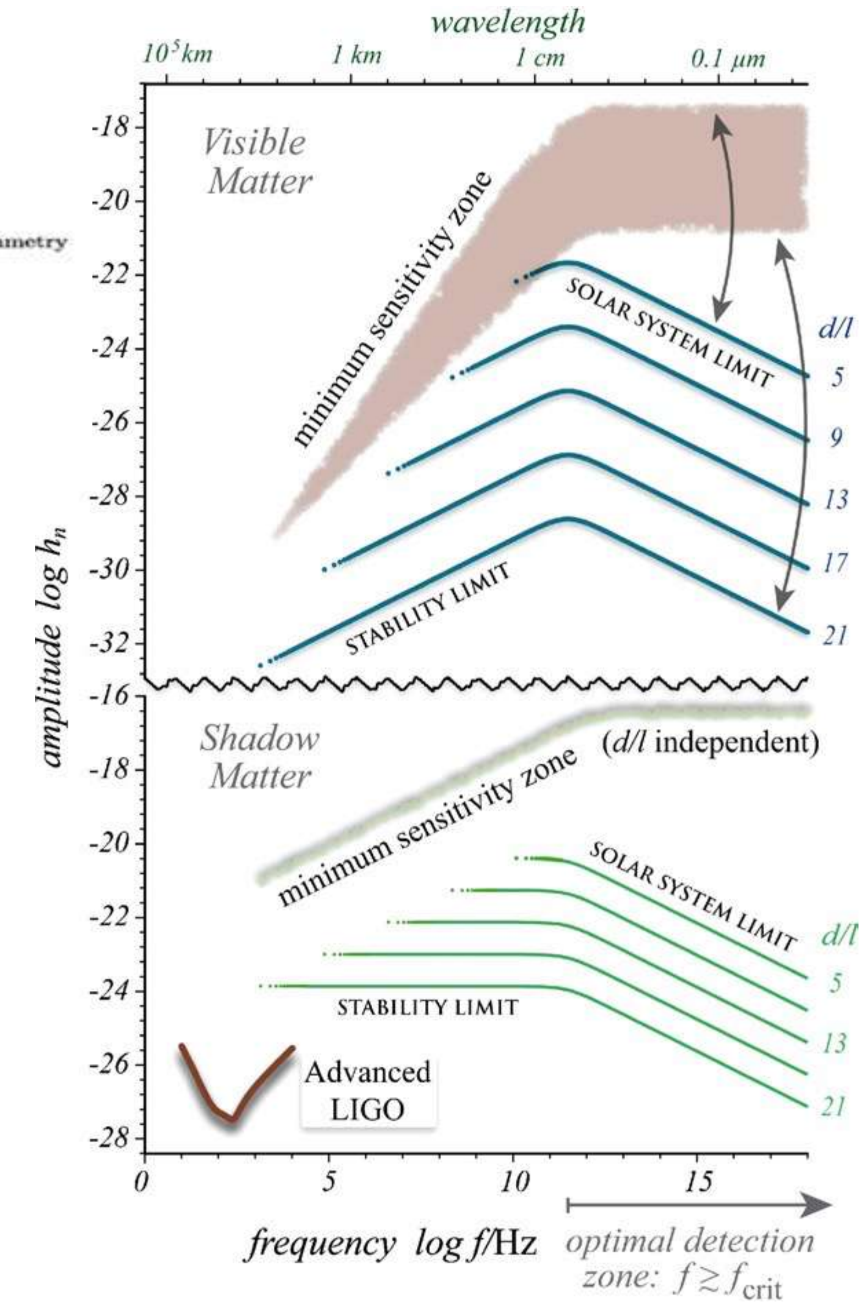


- Pointing: rotatable platform
- BH-BH collisions in higher dimensional gravity

$10 \times$ CAST (B^2L^2A)

$h_c \sim 10^{-28}$ @ $10^{17} - 10^{18}$ Hz





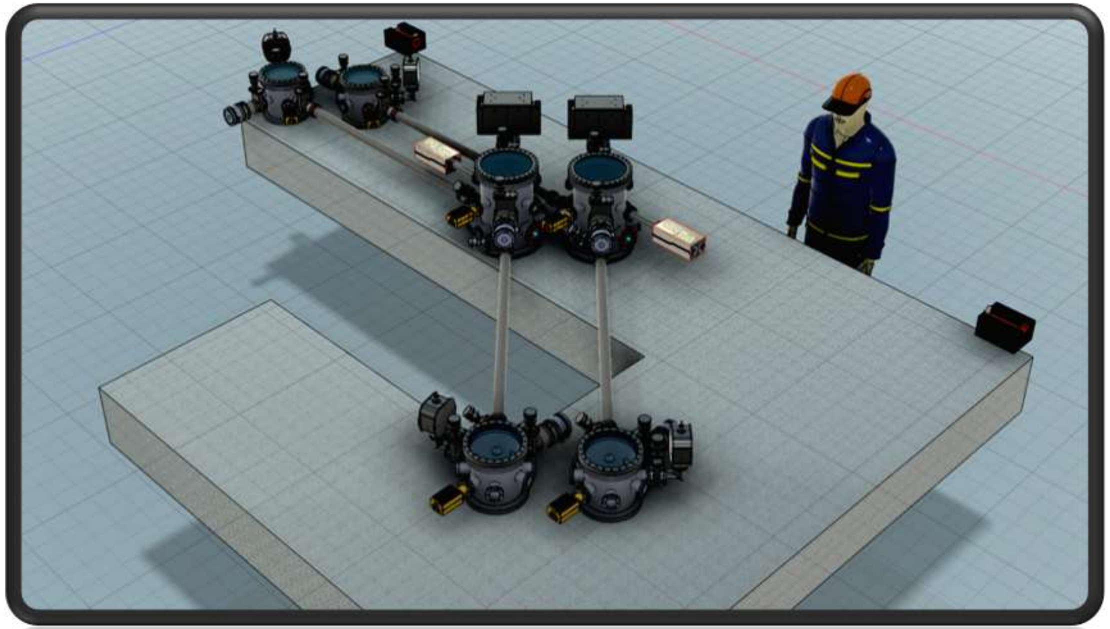
Chris Clarkson and Sanjeev S Seahra
2007 *Class. Quantum Grav.* **24** F33

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

HF GW'S WITH INTERFEROMETRY?

Co-located interferometry up to 250 MHz at Cardiff University

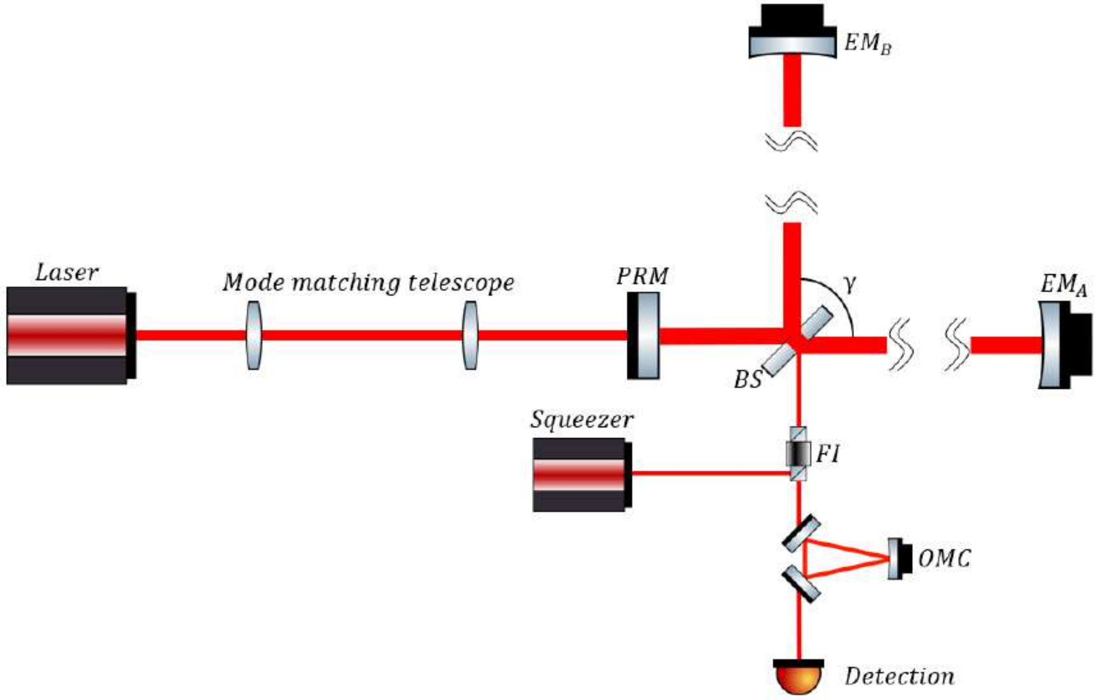
- Quantization of space-time (main scientific goal)
- Dark matter searches
- High-frequency gravitational waves (1 - 250 MHz)



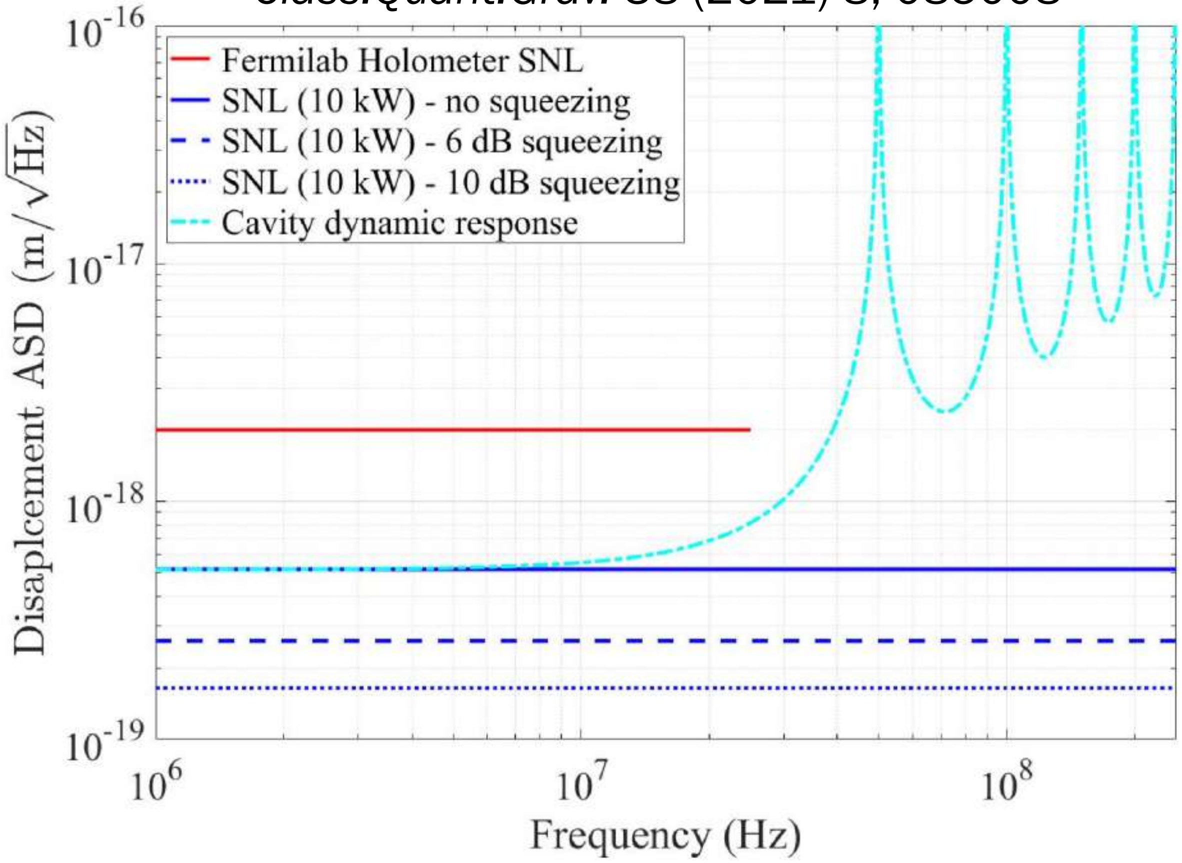
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

QI
Quantum-enhanced Interferometry for New Physics

Co-located interferometry up to 250 MHz



Class.Quant.Grav. 38 (2021) 8, 085008



CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

QI Quantum-enhanced Interferometry for New Physics

Conclusions

Axion search experiments ALPS I, OSQAR and CAST, set first upper limits on stochastic UHF GWs.

The upgraded ALPS II, Baby-IAXO/IAXO, provide infrastructure to improve the existing upper limits for stochastic UHF GWs.

Minor modifications of axion experiments could improve sensitivity to UHF GWs.

Axion search experiments are also being identified as novel UHF GW detectors.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

THANK YOU FOR YOUR ATTENTION