Stimulated emission or absorption of gravitons by light

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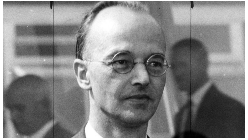
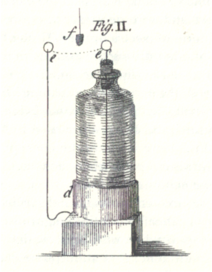
Triest, August 28$^{\mathrm{th}}$ 2026

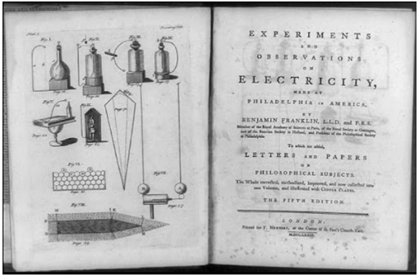
Helmholtz-Zentrum Dresden-Rossendorf (HZDR)



Franklin's Kite Experiment

- unification: lightning $\leftrightarrow$ Leyden jars etc.
- passive observation $\rightarrow$ active manipulation
  - lightning rods
  - power plants
  - etc.





EXPERIMENTS
AND
OBSERVATIONS
ON
ELECTRICITY,
MADE AT
PHILADELPHIA IN AMERICA,
BY
BENJAMIN FRANKLIN, L.L.D. and F.R.S.

To which are added,
LETTERS AND PAPERS
ON
PHILOSOPHICAL SUBJECTS.
The Whole corrected, methodized, improved, and now collected into one Volume, and illustrated with Copper Plates.
THE FIFTH EDITION.

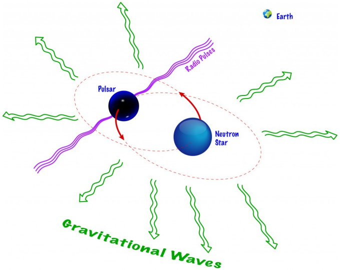
LONDON:

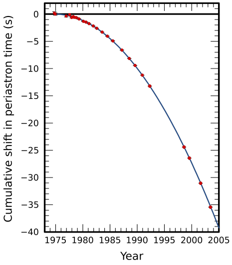
Gravitational Waves

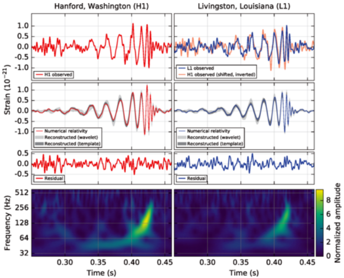
1918 A. Einstein, *Über Gravitationswellen*, Sitzungsber. Preuss. Akad. Wiss. Berlin 154

1974 Hulse-Taylor binary pulsar: energy loss

2015 direct detection at LIGO

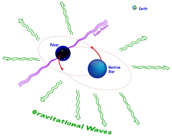


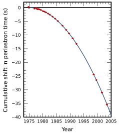




Passive Observation → Active Manipulation?

Hulse-Taylor in the laboratory?





$$P = \frac{G_\mathrm{N}}{45c^5}\sum_{ij}\left(\dddot{Q}_{ij}\right)^2 = \mathcal{O}\left(\frac{G_\mathrm{N}}{c^5}\,\omega^6 m^2 L^4\right)$$

Pre-factor $G_\mathrm{N}/(45c^5) \approx 7 \times 10^{-55}\ \mathrm{s}^3\mathrm{m}^{-3}\mathrm{kg}^{-1}$

comparison to $\hbar \approx 10^{-34}\,\mathrm{Js}$

Goal: emit (or absorb) at least one (ideally many) gravitons with $\hbar\omega$ in a verifiable way

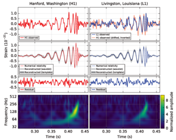
Disclaimer: quantization in units of $\hbar\omega$ is assumed, not proven – nor the aim here

- idea I: go for stimulated emission (or absorption)
- idea II: use light – "optical Weber bar"

Alternative: rotating + vibrating barbell

J. Gräfe, F. Adamietz, R. S., Phys. Rev. D **108**, 064056 (2023)

Energy Transfer: Gravitational $\leftrightarrow$ Electromagnetic Waves



Gravitational wave propagating in z-direction ($+$ polarization, TT gauge)

$$ds^2 = dt^2 - [1+h]dx^2 - [1-h]dy^2 - dz^2 + \mathcal{O}(h^2)$$

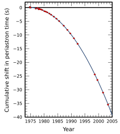
Electromagnetic field polarized in z-direction $\boldsymbol{A}(t,\boldsymbol{r}) = A_z(t,x,y)\boldsymbol{e}_z$

$$\mathcal{L} = \frac{1}{2}\left[(\partial_t A_z)^2 - [1-h](\partial_x A_z)^2 - [1+h](\partial_y A_z)^2\right] \rightsquigarrow \hat{H}_{\text{int}} = h\int d^3r\left[(\partial_y \hat{A}_z)^2 - (\partial_x \hat{A}_z)^2\right]$$

Energy transfer

cf. dispersion relation $\Omega^2 = [1-h]K_x^2 + [1+h]K_y^2$

$$\frac{d\langle\hat{H}\rangle}{dt} = \dot{h}\int d^3r\left\langle(\partial_y \hat{A}_z)^2 - (\partial_x \hat{A}_z)^2\right\rangle$$



- first half-period $\dot{h} > 0$
  - energy loss of photons propagating in x-direction $\to$ emission of gravitons
  - energy gain of photons propagating in y-direction $\to$ absorption of gravitons
- second half-period $\dot{h} < 0$ vice versa

Technische Universität Dresden DRESDEN concept HZDR

Experimental Example Set-up

Gravitational wave
$h = \mathcal{O}(10^{-22})$ and $\omega = \mathcal{O}(\mathrm{kHz})$

Electromagnetic wave
$\Omega = \mathcal{O}(10^{15}\,\mathrm{Hz})$

Frequency shift per photon
$\Delta\Omega = \mathcal{O}(h\Omega) = \mathcal{O}(10^{-7}\,\mathrm{Hz})$

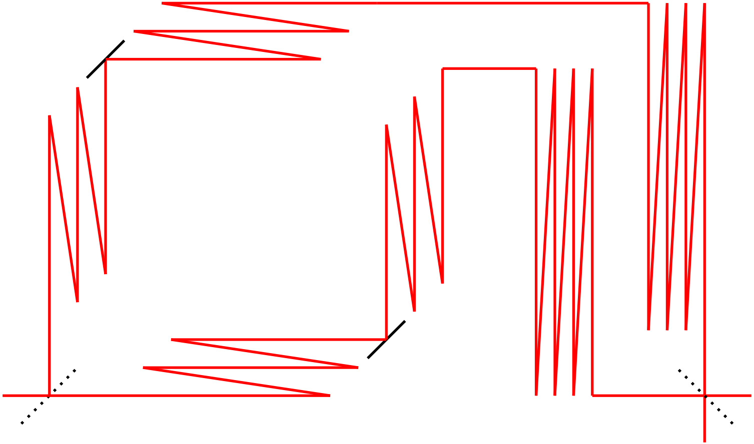
Delay line with $Q = 10^4$
$\mathcal{O}(10^4\,\mathrm{km}) \to \mathcal{O}(0.1\,\mathrm{s})$ or more?

Final phase shift per photon
$\Delta\varphi = \mathcal{O}(10^{-8})$

Poisson limit
$N = \mathcal{O}(10^{16})$ photons

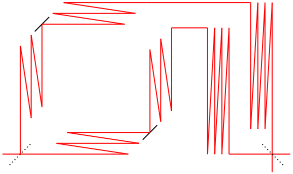
$\to$ many gravitons $\hbar\omega$

Average power $\mathcal{O}(\mathrm{W})$



Non-classical Photon States

Squeezed states enhance sensitivity – extreme example: NOON states



$$|\mathrm{NOON}\rangle = \frac{|N\rangle\,|0\rangle + |0\rangle\,|N\rangle}{\sqrt{2}} \to \frac{e^{+iN\Delta\varphi}\,|N\rangle\,|0\rangle + e^{-iN\Delta\varphi}\,|0\rangle\,|N\rangle}{\sqrt{2}}$$

Heisenberg limit $\Delta\varphi = \mathcal{O}(1/N)$ instead of Poisson limit $\Delta\varphi = \mathcal{O}(1/\sqrt{N})$

Quantum aspects of gravity? entanglement?

$$\frac{|N\rangle\,|0\rangle + |0\rangle\,|N\rangle}{\sqrt{2}}\,\left|\bar{E}_{\mathrm{grav}}\right\rangle \to \frac{e^{+iN\Delta\varphi}\,|N\rangle\,|0\rangle\,\left|\bar{E}_{\mathrm{grav}} - \Delta E\right\rangle + e^{-iN\Delta\varphi}\,|0\rangle\,|N\rangle\,\left|\bar{E}_{\mathrm{grav}} + \Delta E\right\rangle}{\sqrt{2}}$$

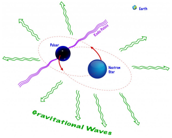
Coherent state $\to$ overlap $\left\langle \bar{E}_{\mathrm{grav}} - \Delta E | \bar{E}_{\mathrm{grav}} + \Delta E \right\rangle \approx 1 \to$ full visibility of photonic interference

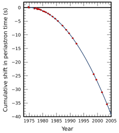
Fock (or thermal) state $\to$ overlap $\left\langle \bar{E}_{\mathrm{grav}} - \Delta E | \bar{E}_{\mathrm{grav}} + \Delta E \right\rangle \ll 1 \to$ no interference

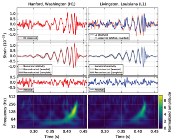
$\to$ gravitational decoherence...

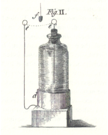
Summary Phys. Rev. Lett. 135, 171501 (2025)

Gravitational waves: passive observation $\rightarrow$ active manipulation "Hulse-Taylor in the laboratory"

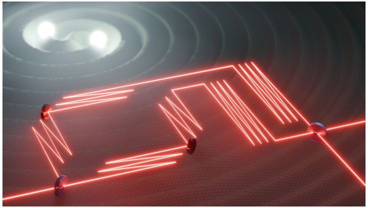







Light in (half) Sagnac interferometer geometry + delay line "optical Weber bar"



Interaction time versus phase accumulation time! stimulated emission of many gravitons $\hbar\omega$

Outlook: non-classical photon states & quantum aspects of gravity (coherent vs Fock state)