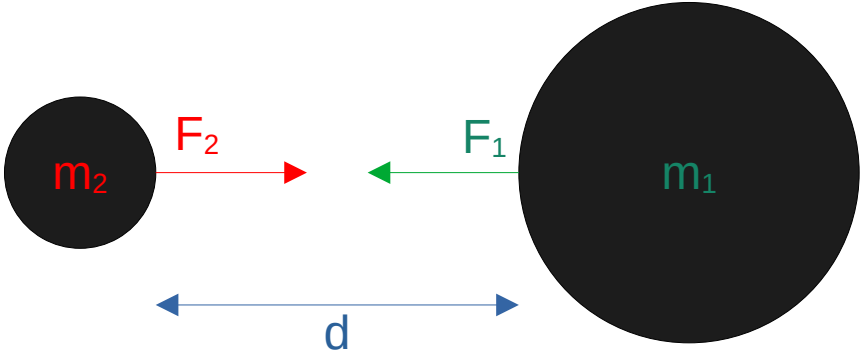
Études de la lumière diffusée dans Virgo

My internship at LAPP on Virgo
under the supervision of Romain Gouaty

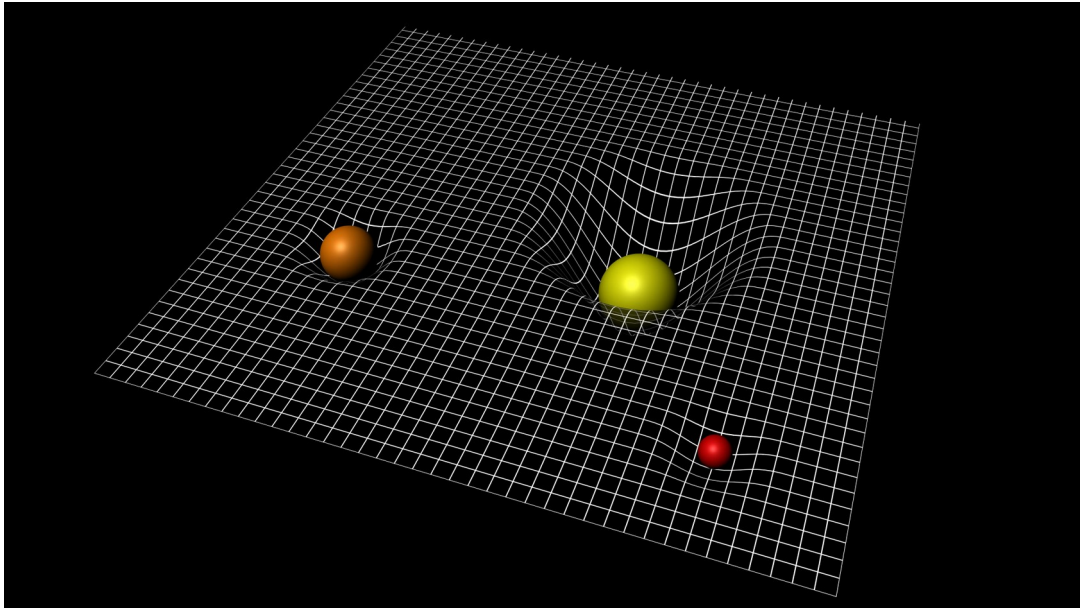
Augustin Demagny

Gravitation and space-time



$$\|F_1\| = \|F_2\| = G \cdot \frac{m_1 \cdot m_2}{d^2}$$

Newton, 1687

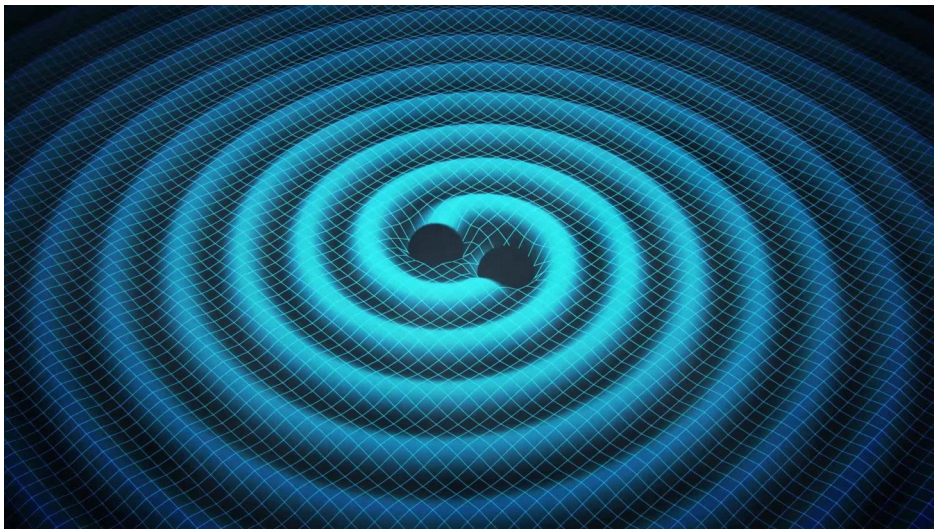


ESA, C. Carreau – ESA Standard Licence

Einstein, 1915

Gravitational wave (GW)

- Space-time deformations
- 2 polarisations (+, x)
- $v = c$
- Amplitude: $A \propto \frac{1}{D}$



Gravitational Wave Illustration
Credit : Swinburne Astronomy Productions

THE SPECTRUM OF GRAVITATIONAL WAVES

esa

Observatories & experiments

Ground-based experiment

Space-based observatory

Pulsar timing array

Cosmic microwave background polarisation

Timescales

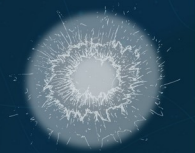
milliseconds — seconds — hours — years — billions of years

Frequency (Hz)

100 — 1 — 10^{-2} — 10^{-4} — 10^{-6} — 10^{-8} — 10^{-16}

Cosmic fluctuations in the early Universe

Cosmic sources

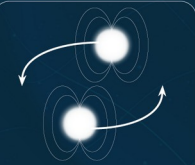


Supernova

Pulsar

Compact object falling onto a supermassive black hole

Merging supermassive black holes



Merging neutron stars in other galaxies

Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

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#lisa

Crédit : ESA

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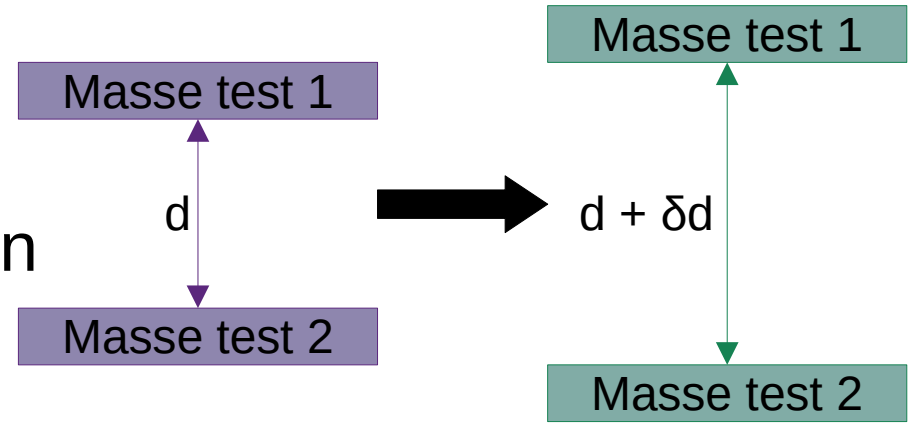
Detection principle

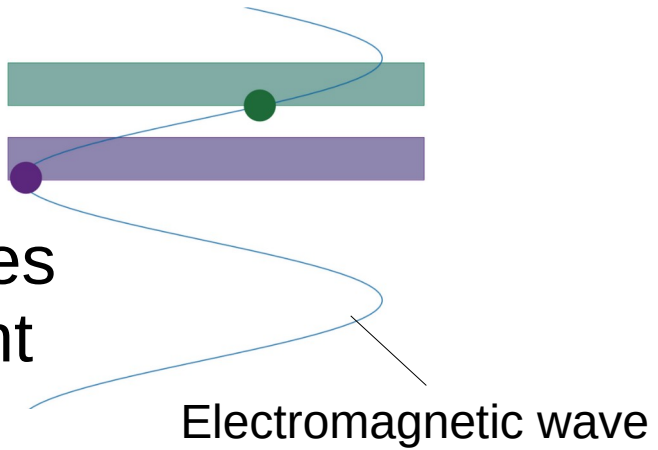
Gravitational wave

- ➔ Space-time deformations
- ➔ Change the distance between two masses

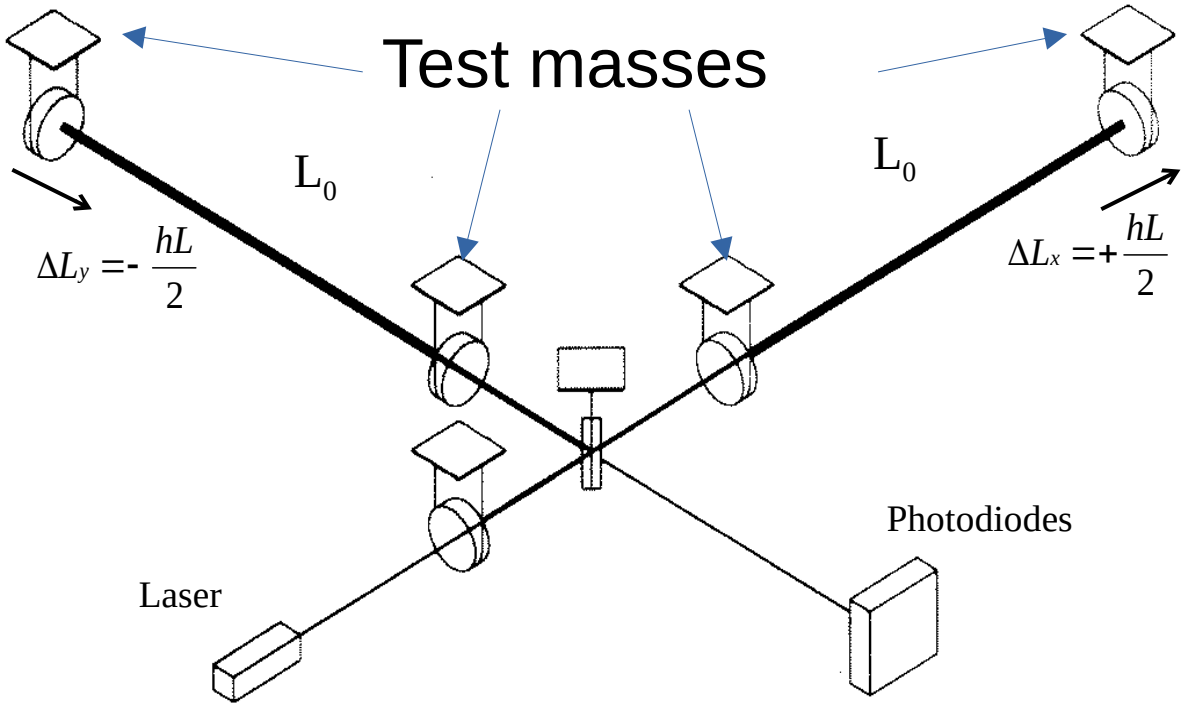


Invisible to the naked eye

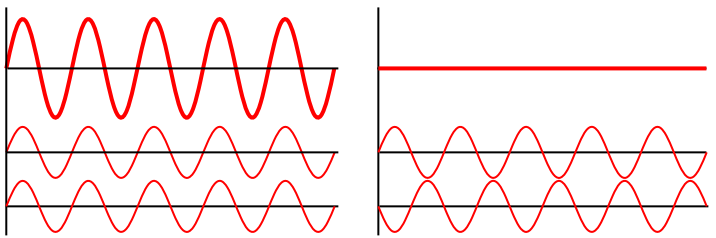
- Use of electromagnetic waves to measure this displacement



How a gravitational-wave detector works

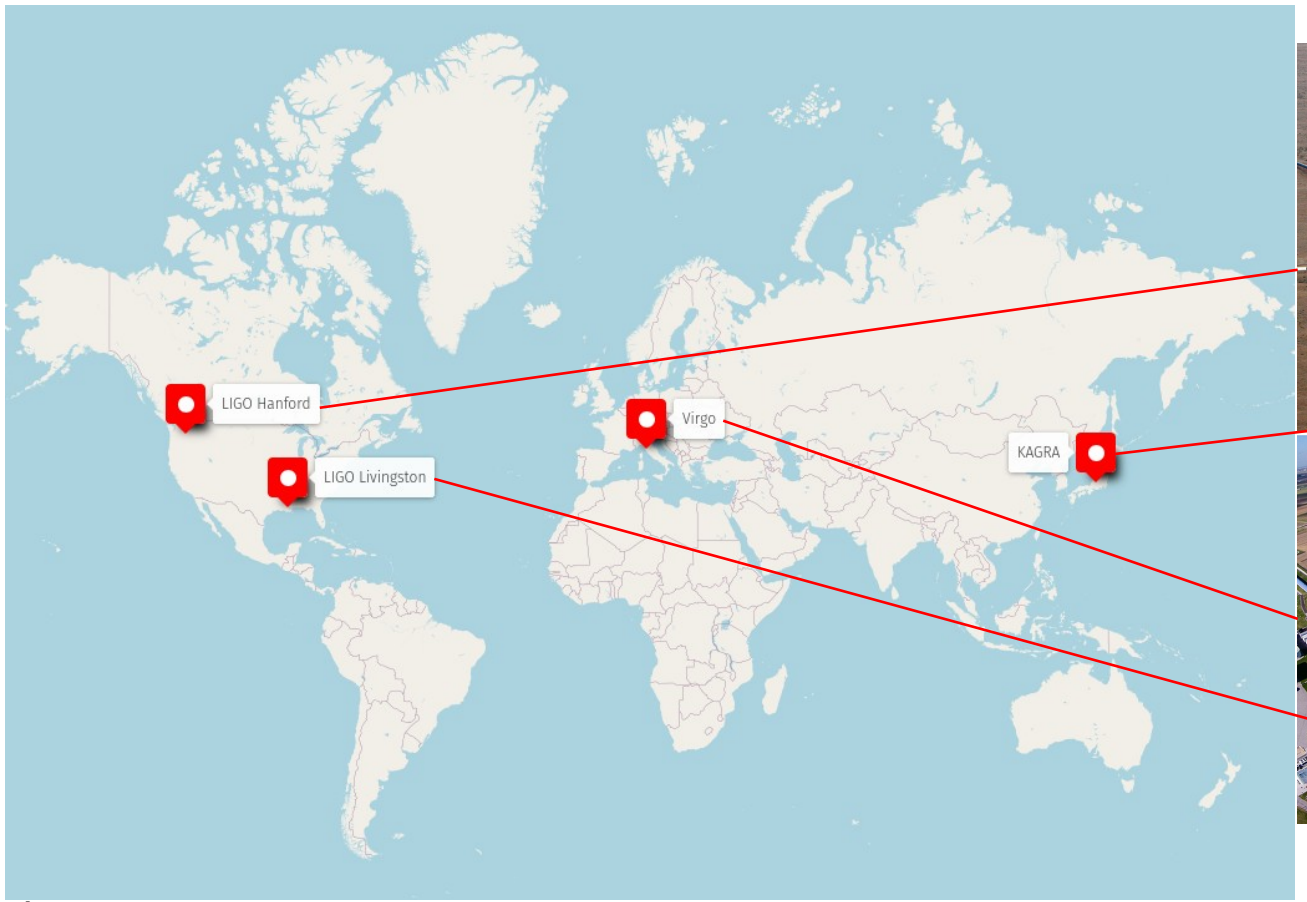


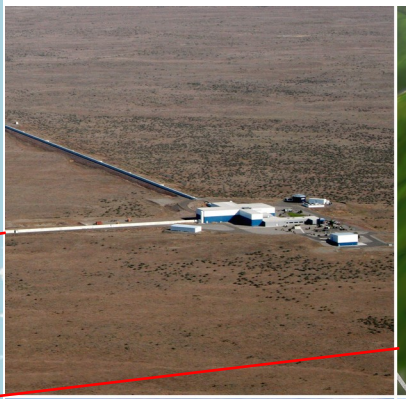
Interference :

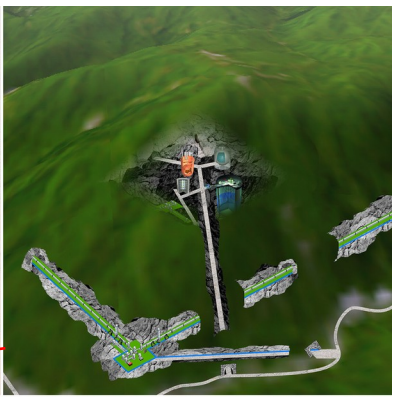


⇒ Change in power observed on the black fringe

LIGO-Virgo-Kagra collaboration

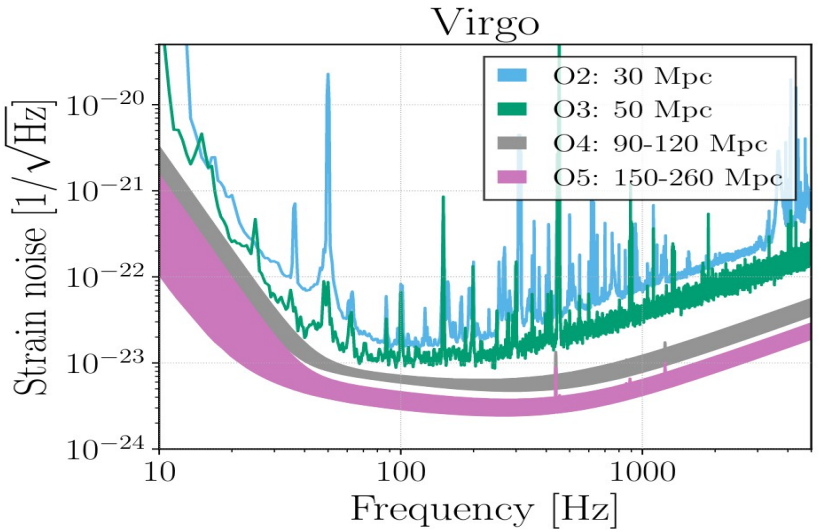


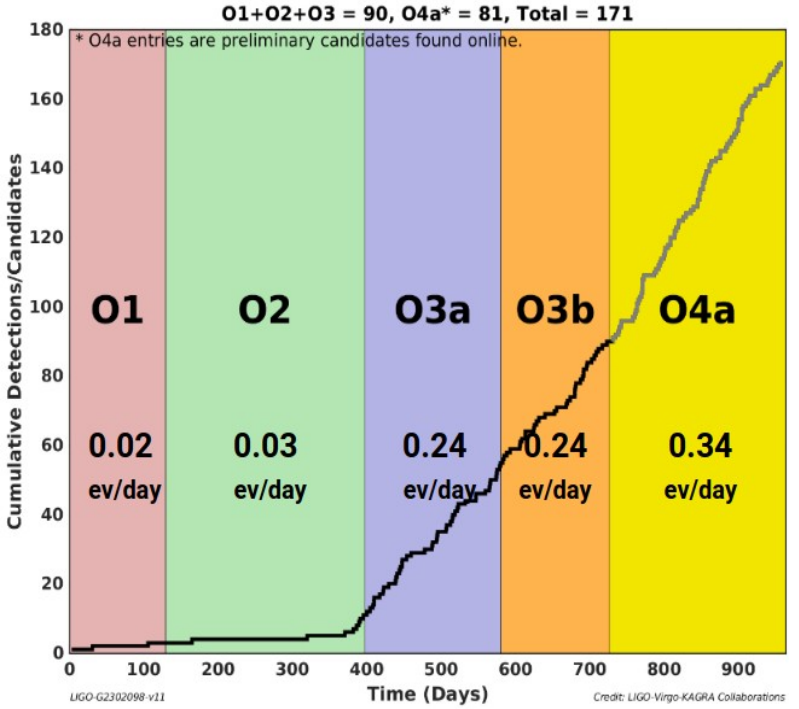




Scientific results : Virgo/LIGO

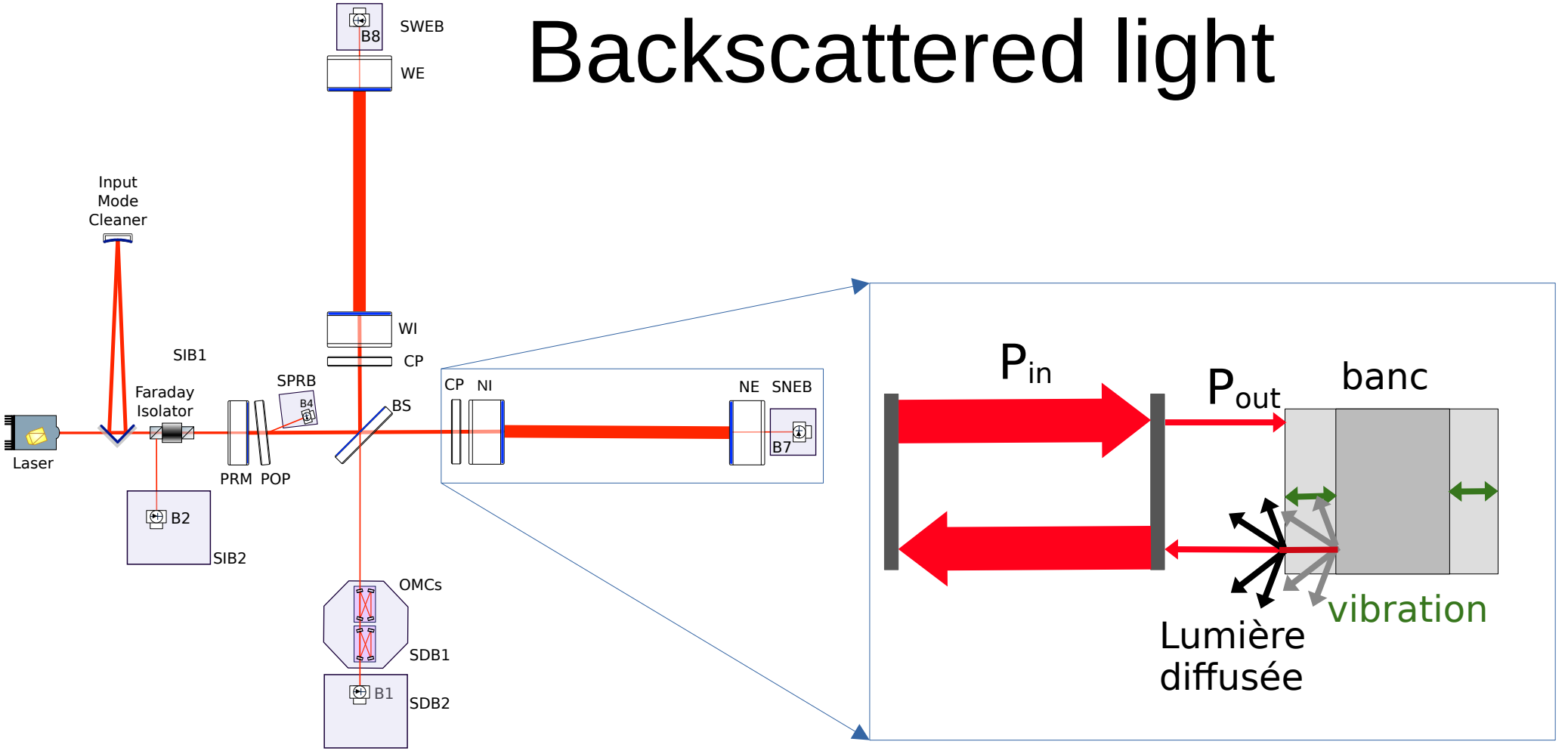
- 171 gravitational waves detected
- Virgo's sensitivity improves with each campaign





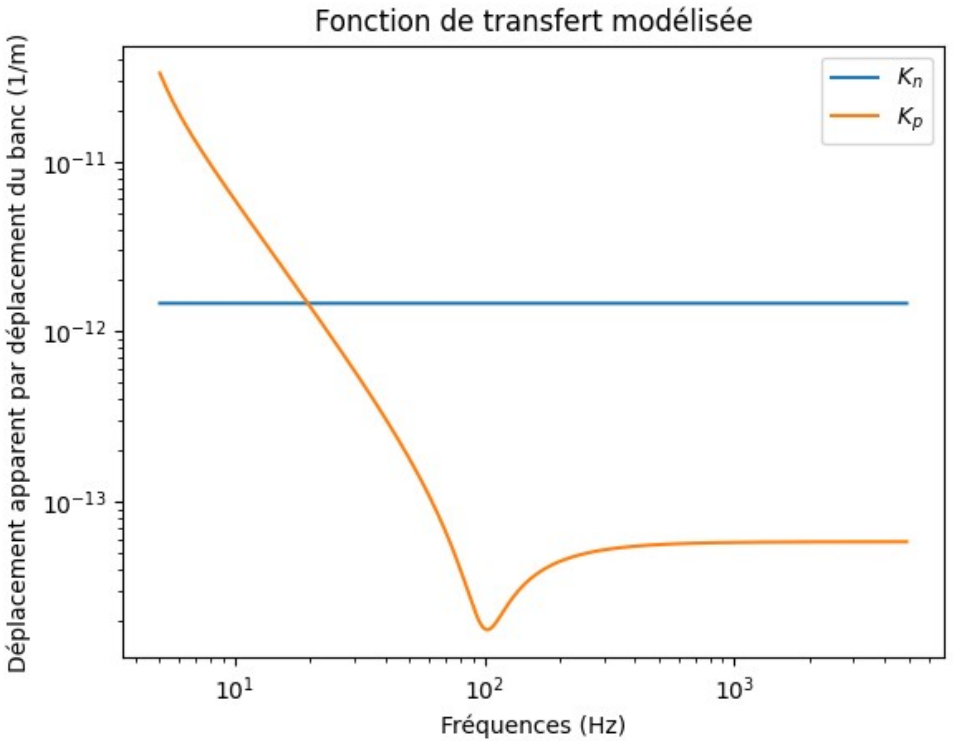
Duration and cumulative number of detections of LIGO/Virgo observations

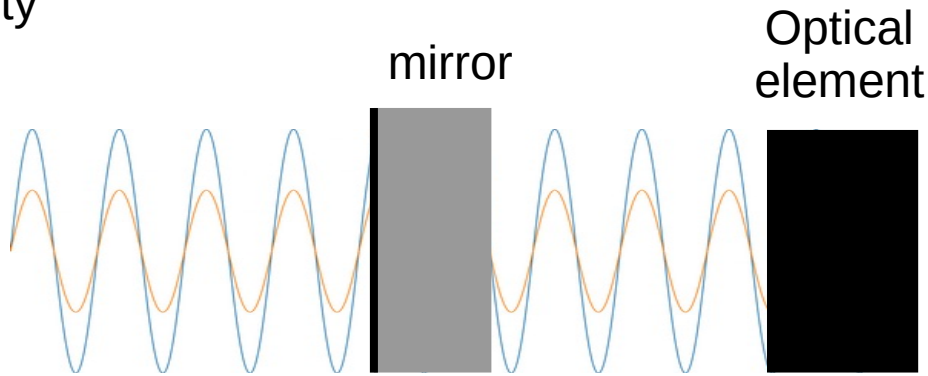
Backscattered light



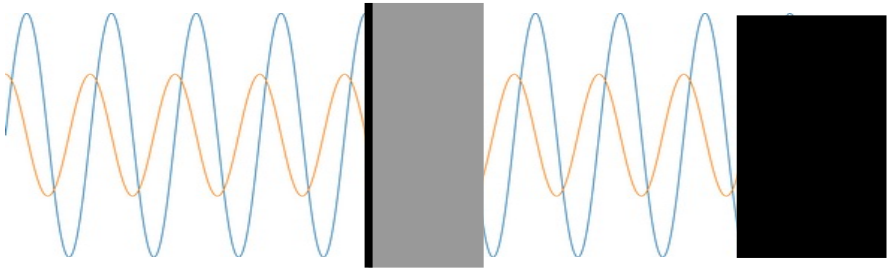
Coupling transfer functions

Different coupling types: different effects on sensitivity





Power difference: radiation pressure



Phase noise: alters detector measurement by interference

Couplage de la lumière diffusée

sensitivity

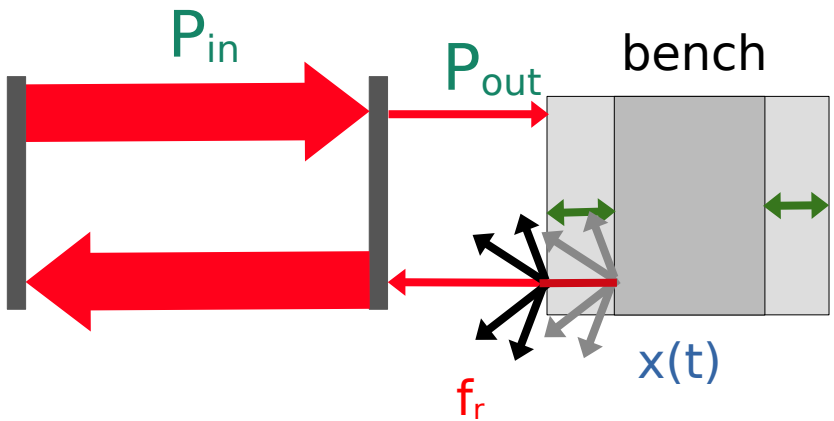
Mirror transmission

Bench movement

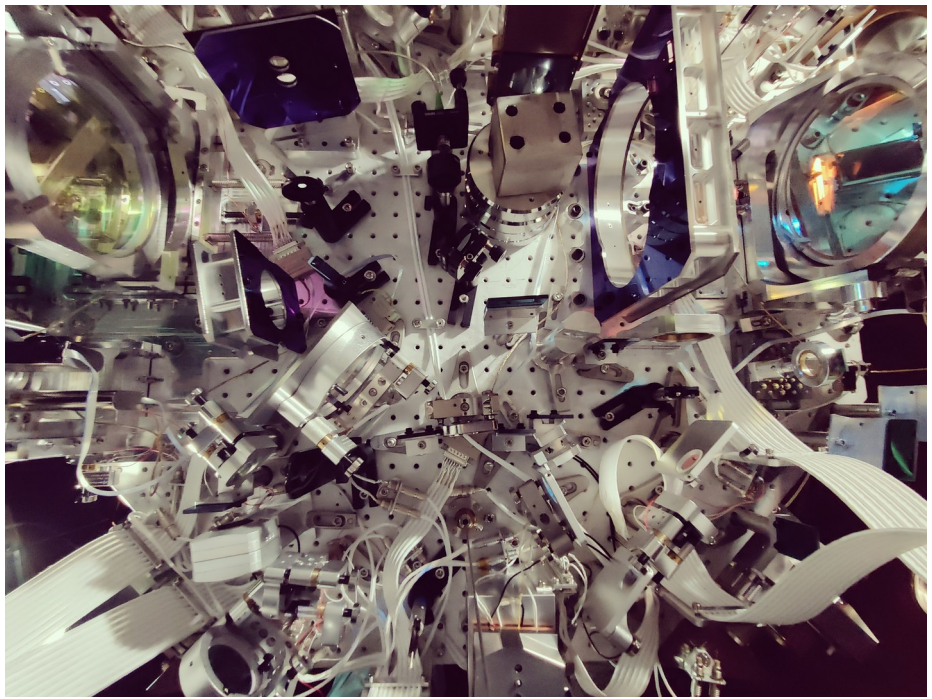
$$h_r(f) = \sqrt{f_r} \cdot \frac{P_{out}}{P_{in}} \cdot \{ K_n(f) \cdot \mathcal{F}[\sin(\frac{4 \cdot \pi}{\lambda}(x(t)))] + K_P(f) \mathcal{F}[\cos(\frac{4 \cdot \pi}{\lambda}(x(t)))] \}$$

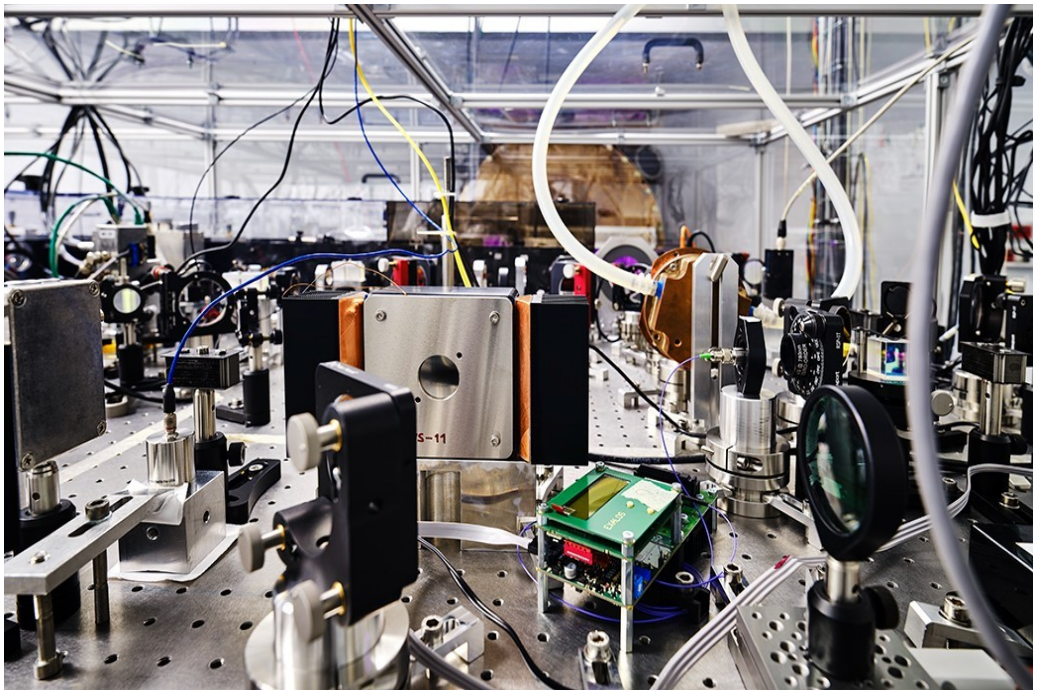
Fraction of backscattered light

Transfer function by radiation pressure (Kp) and phase (Kn)



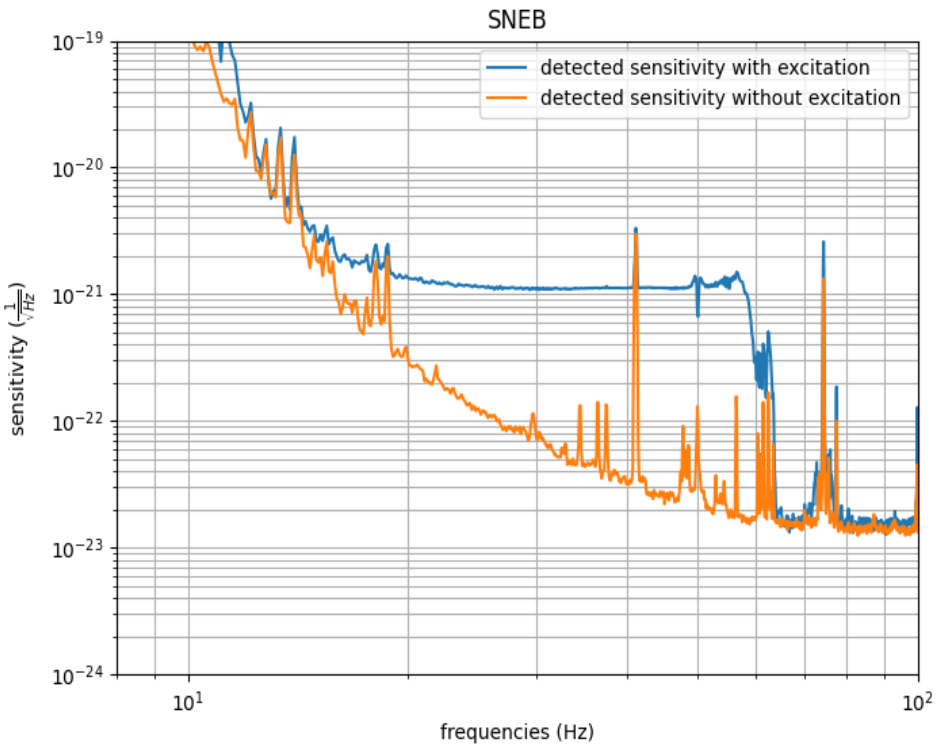
Vibration of benches

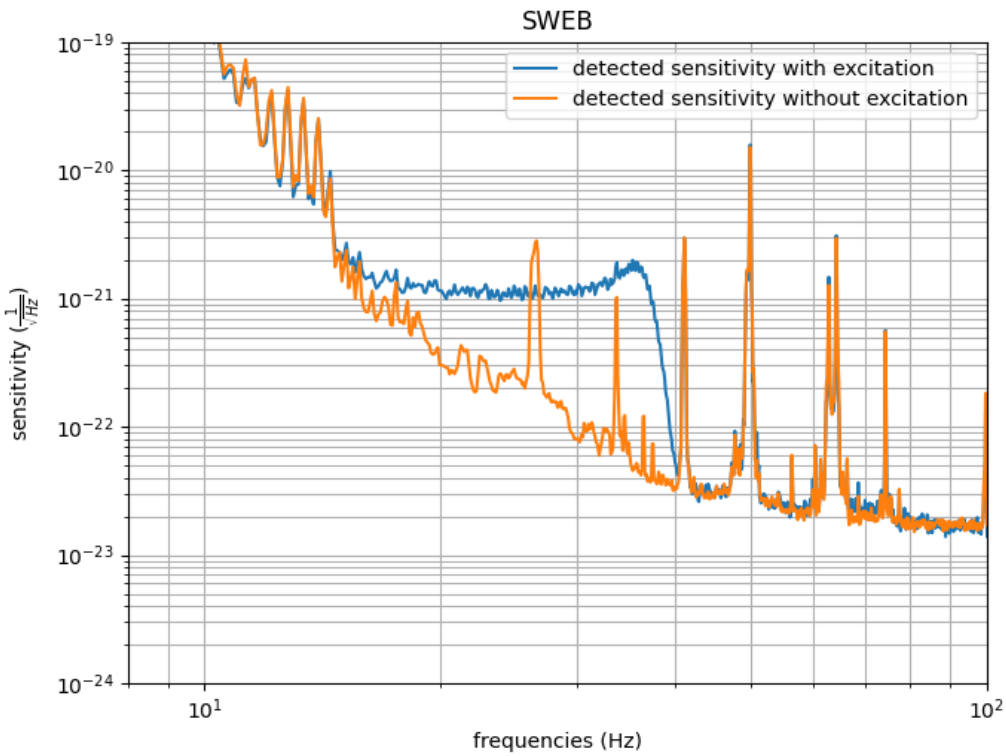




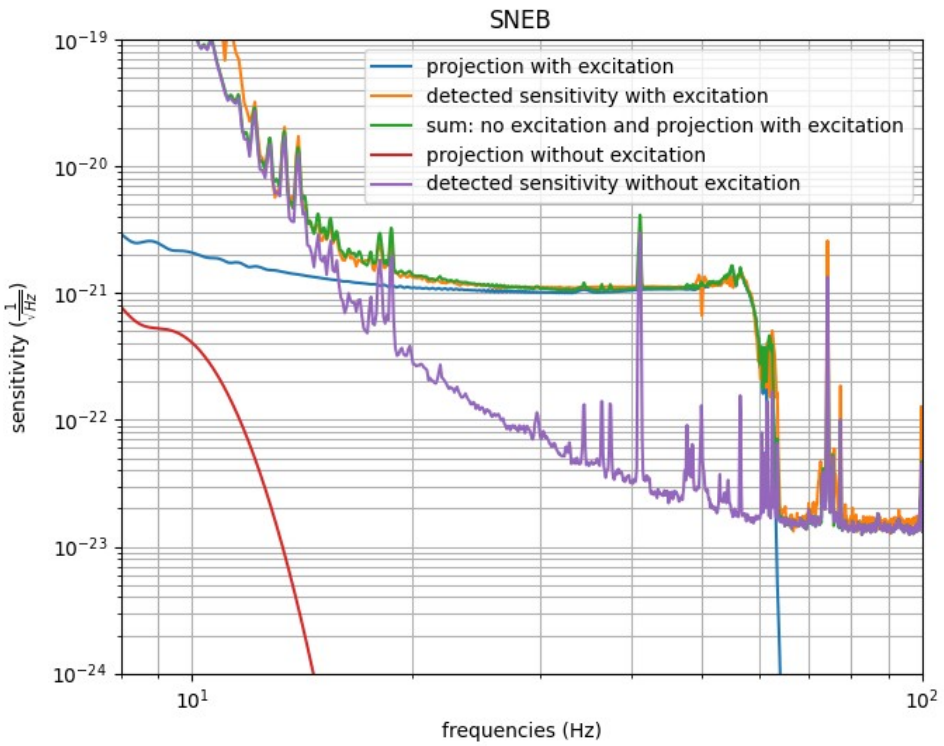
Shaking up optical benches

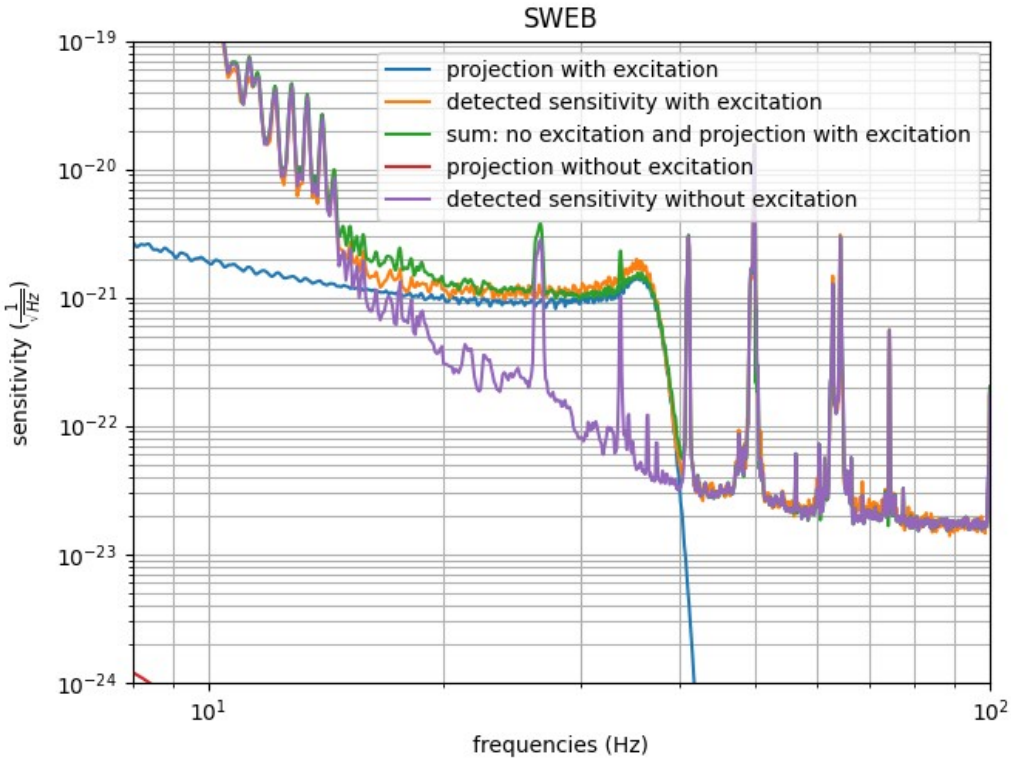
Taking data


SNEB
detected sensitivity with excitation
detected sensitivity without excitation
sensitivity ($\frac{1}{\sqrt{Hz}}$)
frequencies (Hz)


SWEB
detected sensitivity with excitation
detected sensitivity without excitation
sensitivity ($\frac{1}{\sqrt{Hz}}$)
frequencies (Hz)

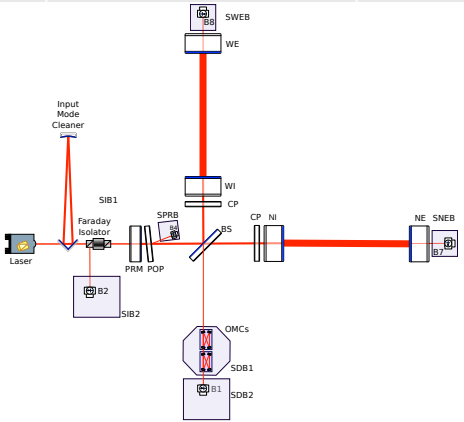
Fit between projection and data

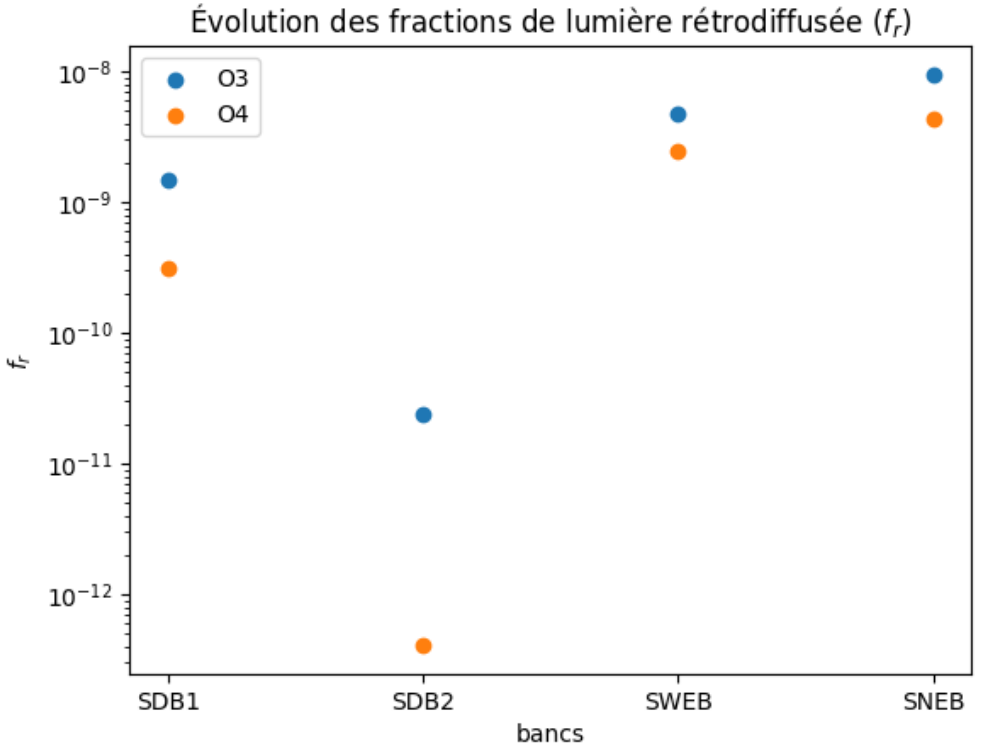




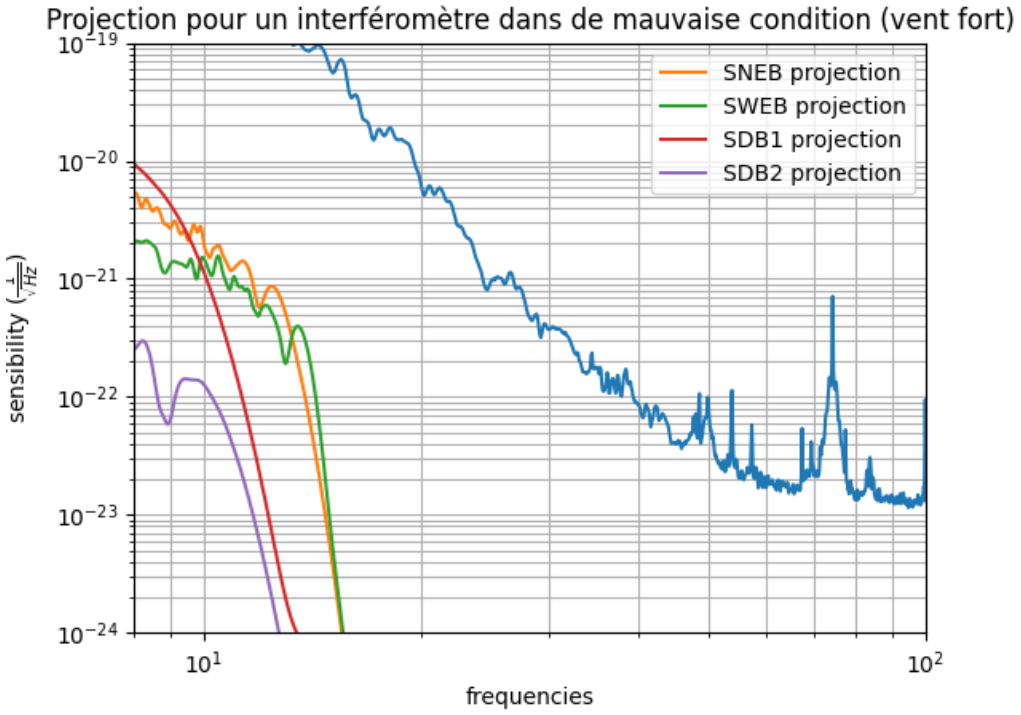
Projection computation results

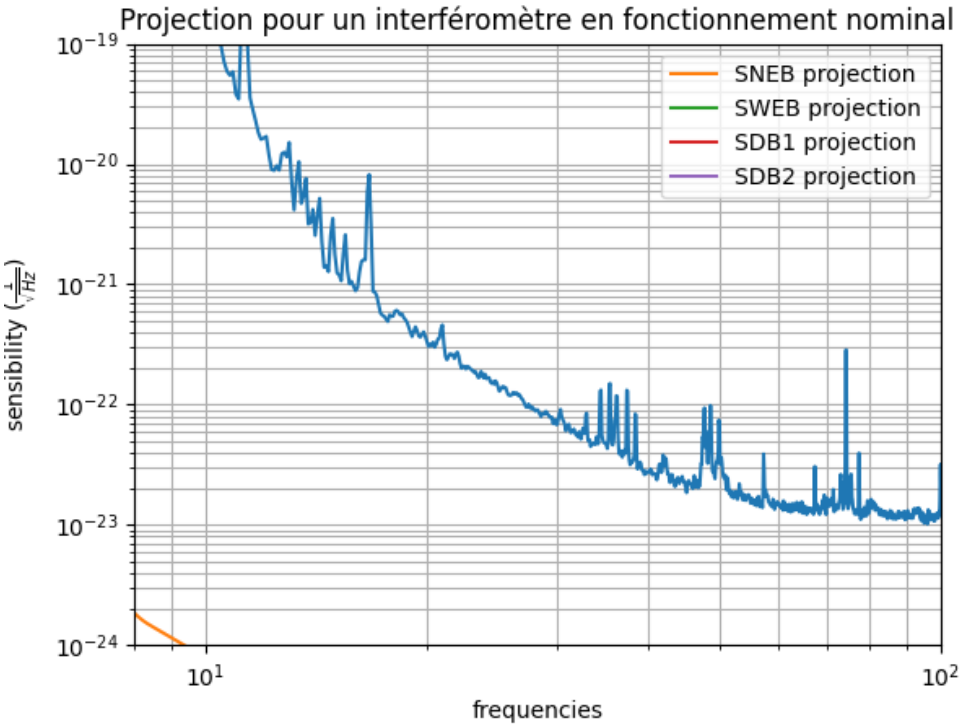
banc	f_r (O3)	f_r (O4)
SDB1	$1{,}5 \cdot 10^{-9}$	$3{,}1 \cdot 10^{-10}$
SDB2	$2.4 \cdot 10^{-11}$	$4{,}1 \cdot 10^{-13}$
SWEB	$4{,}7 \cdot 10^{-9}$	$2{,}5 \cdot 10^{-9}$
SNEB	$9{,}5 \cdot 10^{-9}$	$4{,}4 \cdot 10^{-9}$





Effect of backscattering on sensitivity





Thank you !

Any questions ?