BROADBAND

RESONANT MASS
GW DETECTOR

the "DUAL SPHERE"

concept : NOT (yet)
a feasibility study

attractive :

- sensitive @ high frequencies (kHz)
- complementary to "advanced" ifo

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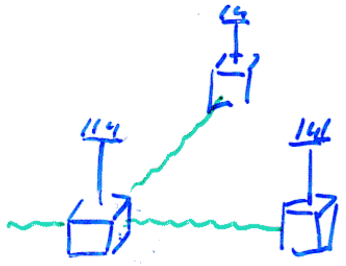
OPTOMECHANICAL G.W. DETECTORS



km BASELINE
INTERFEROMETERS

"WIDE" BAND
$\Delta f \sim f$

CRYOGENIC RESONANT BARS
WITH RESONANT OPTOMECHANICAL
TRANSDUCER

"NARROW" BAND $\Delta f \simeq 0.1\, f$

a third possibility:

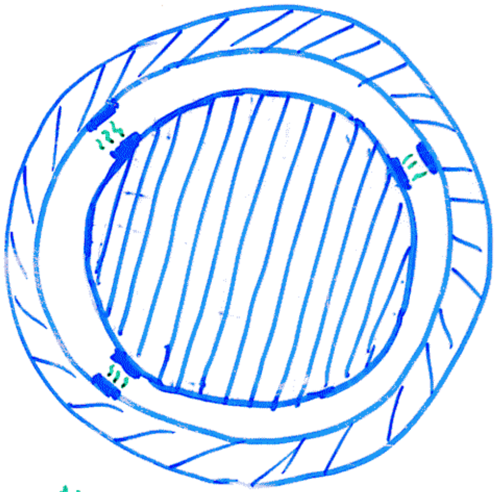
NON RESONANT OPTICAL READOUT + MASSIVE RESONANT SPHERES

↳ "WIDE" BAND

CONCENTRIC
FULL + HOLLOW SPHERE

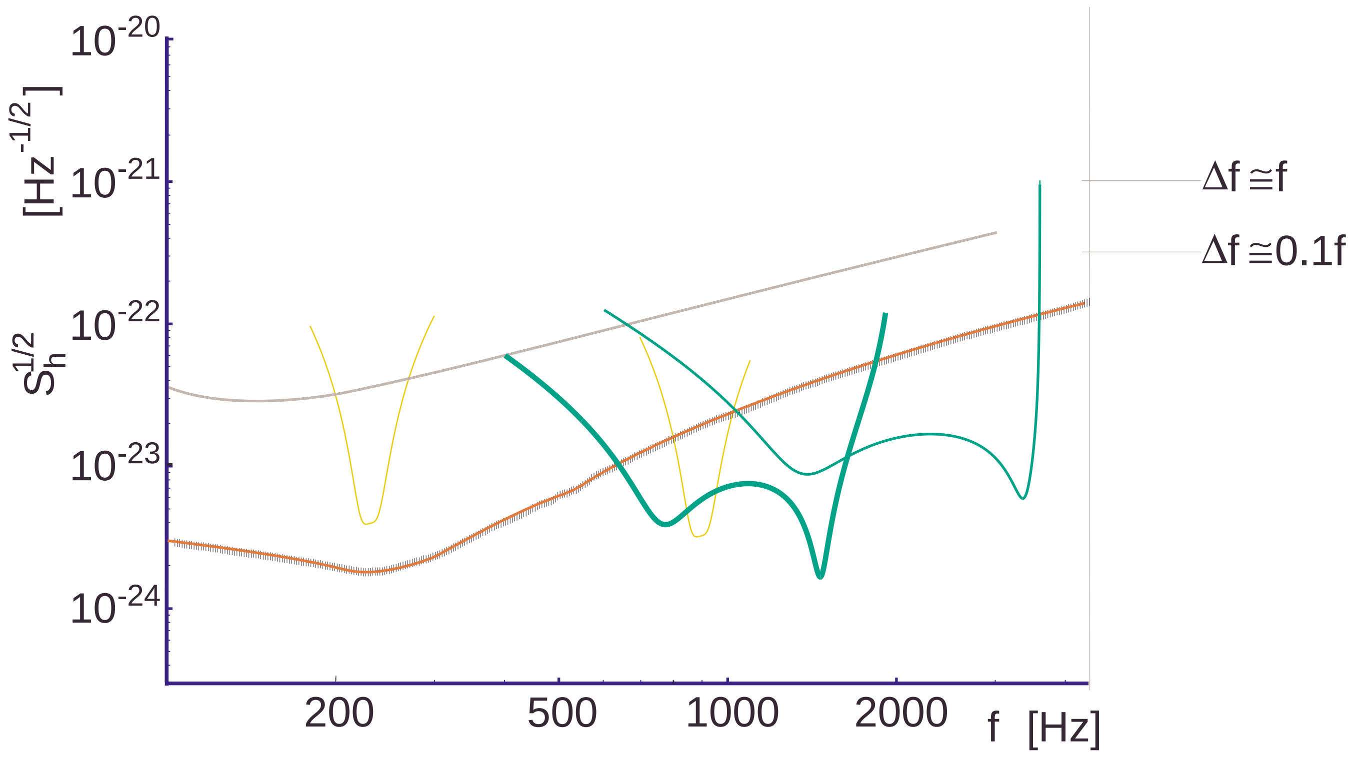
{ sapphire, YAG, Si ~3 m
30 t + 30 t }

FABRY-PEROT CAVITIES



low losses 1 ppm
high finess 3×10^5
high laser power 1 W

$S_h^{1/2}(f) \simeq 1 \times 10^{-23}\ Hz^{-1/2}$ $\quad 1000\ Hz \lesssim f \lesssim 3000\ Hz$



LIGO I , VIRGO

LIGO II

$CuAl^{10\%}$ hollow sphere 4.4 m diameter
resonant transducer and SQL

sapphire "dual spheres" Q/T ~ 5 10^8 K^{-1} and SQL
FP cavities: 2 cm *F* ~ 10^6

100 t + 100 t 4.6 m diameter P_{in} ~ 3 W

30 t + 8 t 2.3 m diameter P_{in} ~ 8 W

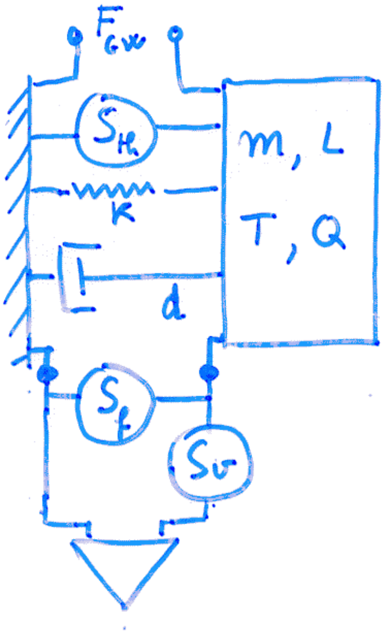
resonant mass gw detectors are quoted
as "INTRISECALLY NARROW BAND"

are they? NO! ↙ ↙ YES IN PRACTICE

multimode $n \gtrsim 3 \Rightarrow \Delta f \sim f$

BUT in operation until now $n = 2 \Rightarrow \Delta f \lesssim 0.1 f$

a "ONE MODE" detector Price PR D36 (87)



res. mass

$$\omega_0 = \sqrt{\frac{K}{m}} \qquad d = \frac{\omega_0 m}{Q}$$

$$F_{GW}(\omega) = \frac{2}{\pi^2} m L \omega^2 h(\omega)$$

$$S_{H}(\omega) = 2 K_B T d$$

mech. amplifier

$$S_v(\omega) = \omega^2 S_x(\omega)$$ ← displ. noise

$S_f(\omega) \rightarrow$ "back action"

$$\sqrt{S_f S_v} = K_B T_N \qquad \sqrt{\frac{S_f}{S_v}} = Z_n$$

$$S_f = K_B T_N Z_n$$

best performance: "LOSSLESS LIMIT"

$$S_{H}(\omega) \ll S_f(\omega) \Rightarrow Q \gg \frac{2T}{T_n} \frac{\omega_0 m}{Z_n}$$

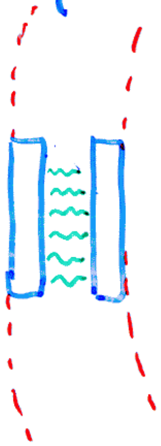
$$\hookrightarrow \frac{\Delta f}{f} = \frac{Z_n}{\omega_0 m}$$

$\{ SQL \Rightarrow T_n \simeq \hbar \omega_0 \}$

at the time (SQUIDs) $\frac{Z_n}{\omega_0 m} \approx 10^{-5} - 10^{-7}$

NON-resonant optomechanical transducer
reading motion of RESONANT mass(es)

↳ (mechanically non-resonant version of: CONTI et al RSI 69 (98))



Fabry-Perot cavity

"short" ~ 1 cm

low loss ~ 1 ppm

high finesse $\mathfrak{F} \approx 10^6$

high input power $P \approx 10$ W

$$\lambda_n \equiv \sqrt{\frac{S_f}{\omega^2 S_x}} \simeq B \frac{\mathfrak{F}^2 P}{\omega_0}$$

$B(\nu_{laser}, \eta, A_{mod}) \approx 4 \times 10^{-3}$ s/m², $m \sim$ tons, $\frac{\omega_0}{2\pi} \sim$ kHz

$$\frac{\Delta f}{f} \equiv \frac{\lambda_n}{\omega_0 m} \approx 0.1$$

suggest that the bandwidth
can be much BROADER!

- each F-P cavity mirror part of a low thermal noise mechanical system $\Rightarrow$ DUAL SPHERE
- "omnidirectional" sensitivity $\Rightarrow$ 6 cavities (TIGA), 5 " (Lobo) — sense RADIAL displ.
- readout SQL: $\frac{K_B T}{Q} \lesssim \hbar \Delta f \Rightarrow \Delta f \sim f \quad \frac{Q}{T} \gtrsim 10^8 K^{-1}$
- Large "cross section" $\sim \rho v_s^5 \Rightarrow$ CuAl$^{10\%}$, YAG, Si, SAPPHIRE

RADIAL DISPLACEMENT $x(\omega) \propto \omega^2 \tilde{h}(\omega)$

- write: $S_x(\omega)$ as due to thermal + back-action and to ALL modes (also those non-gw sensitive)

  ω_{ne}^{hollow}, ω_{ne}^{full}

- find:

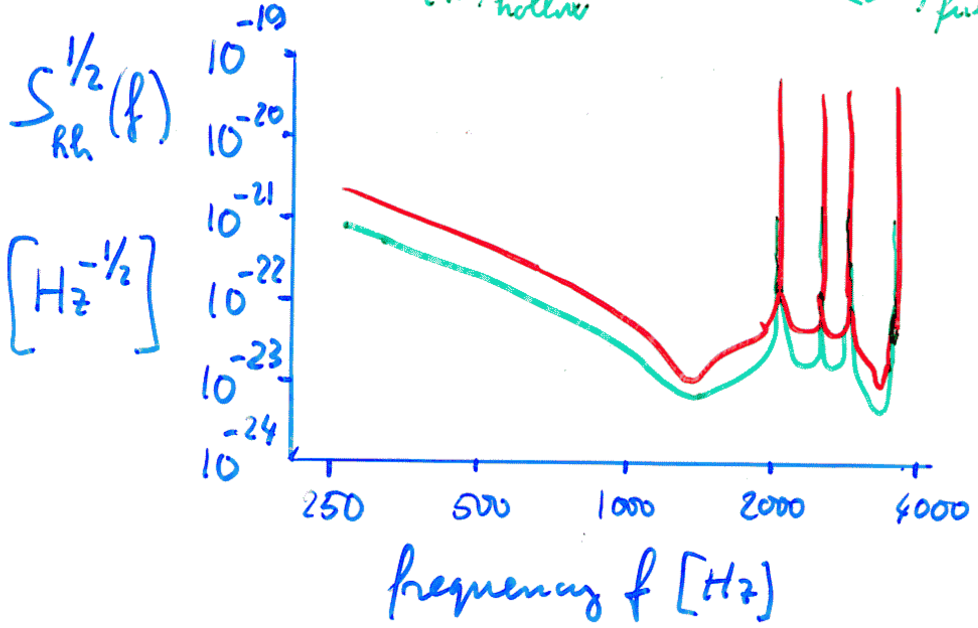
$$S_h(\omega) = \frac{S_{x,hollow}^{th+ba}(\omega) + S_{x,full}^{th+ba}(\omega) + S_x^{shot}(\omega)}{\left| x_{hollow}(\omega) - x_{full}(\omega) \right|^2 / \left| \tilde{h}(\omega) \right|^2}$$

- for $\omega_{hollow} < \omega < \omega_{full}$ signals ADD
- for some $\omega^* > \omega_{hollow}, \omega_{full}$ signal CANCEL

sapphire 2.6 m o.d. 30+8 tons

"DUAL SPHERE" spectral strain noise

$\left(\frac{\omega_0}{2\pi}\right)_{hollow} = 1300\ Hz$ $\left(\frac{\omega_0}{2\pi}\right)_{full} = 3370\ Hz$



— "light" SQL @ 1500 Hz $\frac{Q}{T} = 5\times10^{8}\ K^{-1}$ P=8W

— thermal + shot noise regime $\frac{Q}{T} = 10^{8}\ K^{-1}$ P = 1W

notice

- few NON-GW active resonances → thermal noise
- 1300 Hz < f < 3370 Hz signal drives hollow sphere ABOVE resonance and full sphere BELOW resonance → DIFFERENTIAL MOTION TRANSDUCER READS SUM OF RESPONSES
- f ~ 4000 Hz → RESPONSES CANCEL OUT

before an actual feasibility study: show stoppers ???

- FABRICATION — preserving $Q \gtrsim 10^8$
  CuAl 1%
  YAG, Si, Al_2O_3, silicate, SAB bonded
- CRYOGENICS — cool to $T \sim 1K$ and drag out few watts
- SUSPENSIONS — $m \gtrsim 10t$ — "freely" one sphere in respect to the other
- CRYOPTICS — F-P cavities demonstrated at low T — but at lower $\mathcal{F}$ and much lower P
- √ THERMOELASTIC NOISE — ok
- ?...............? — coating th. noise?