STATE OF THE ART IN LIGO

NEW TOPOLOGIES

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LIGO-G030143-00-Z

IV. NEW TOPOLOGIES FOR LIGO-III

1. Standard LIGO-II signal-recycling topology + optical rigidity.

2. New QND topologies.

Bifurcation:

2a. Topologies with the traditional out-of-cavity readout meter	2b. Topologies with QND intracavity readout meter

Characteristic energy:

$$\mathcal{E}_{\rm SQL} = \frac{ML^2\Omega^3}{2\omega_o}$$

$$\approx 40\text{J} \times \left(\frac{M}{40\text{Kg}}\right)\left(\frac{L}{4\text{Km}}\right)^2\left(\frac{\Omega}{2\pi\times 100\text{s}^{-1}}\right)^3$$

and circulating power:

$$W_{\rm SQL} = \frac{MLc\Omega^3}{8\omega_o}$$

$$\approx 0.75\text{MWt} \times \left(\frac{M}{40\text{Kg}}\right)\left(\frac{L}{4\text{Km}}\right)\left(\frac{\Omega}{2\pi\times 100\text{s}^{-1}}\right)^3$$

1. Standard LIGO-II signal-recycling topology + optical rigidity.

V.B.Braginsky, F.Ya.Khalili, "Low-noise rigidity in quantum measurements", Phys. Lett. **A257** (1999) 241

F.Ya.Khalili, "Frequency-dependent rigidity in large-scale interferometric gravitational-wave detectors", Phys. Lett. **A288** (2001) 251

A.Buonanno, Yanbei Chen, "Quantum noise in second generation, signal-recycled laser interferometric gravitational-wave detectors", Phys. Rev. **D64** (2001) 042006

A.Buonanno, Yanbei Chen, "Signal recycled laser-interferometer gravitational-wave detectors as optical springs", Phys. Rev. **D65** (2002) 042001

Advantages: Relatively simple methods which require only minimal modifications of the LIGO design; does not require any increase of the optical power.

Disadvantages: Only modest gain in sensitivity can be obtained in the wide band, or large gain in the narrow band.

Our opinion: Could (and should) be implemented already in the LIGO-II stage?

2a. Topologies with the traditional out-of-cavity readout meter

V.B.Braginsky, M.L.Gorodetsky, F.Ya.Khalili and K.S.Thorne, "Dual-resonator speed meter for a free test mass", Phys. Rev. **D61** (2000) 044002

H.J.Kimble, Yu.Levin, A.B.Matsko, K.S.Thorne and S.P.Vyatchanin, "Conversion of conventional gravitational-wave interferometers into QND interferometers by modifying their input and/or output optics", Phys. Rev. **D65** (2002) 022002

P.Purdue, "An analysis of a QND speed-meter interferometer", Phys. Rev. **D 66** (2002) 022001

P.Purdue and Yanbei Chen, "Practical speed meter design for QND gravitational-wave interferometers", Phys. Rev. **D 66** (2002) 122004

Yanbei Chen, "Practical speed meter design for QND gravitational-wave interferometers", LANL preprint gr-qc/0208051 (2002)

F.Ya.Khalili, "Quantum speedmeter and laser interferometric gravitational-wave antennae", LANL preprint gr-gc/0211088 (2002)

Advantages: The main design of the LIGO interferometer still preserved, and sensitivity in not limited by an SQL of any kind.

Disadvantages: Due to the EQL, circulating optical power depends sharply on the required sensitivity:

$$W \approx \zeta^2 \frac{W_{\text{SQL}}}{2}\left(\frac{h_{\text{SQL}}}{h}\right)^2 \approx \zeta^2 \times 0.4\,\text{MWt} \times \left(\frac{h_{\text{SQL}}}{h}\right)^2,$$

where $\zeta < 1$ is the squeezing factor of the input field in the dark port.

Our opinion: Who will provide squeezed state?

2b. Topologies with QND intracavity readout meter

V.B.Braginsky, F.Ya.Khalili, "Nonlinear meter for the gravitational wave antenna", Phys. Lett. **A218** (1996) 167

V.B.Braginsky, M.L.Gorodetsky, F.Ya.Khalili, "Optical bars in gravitational wave antenna", Phys. Lett. **A232** (1997) 340

V.B.Braginsky, M.L.Gorodetsky, F.Ya.Khalili, "Quantum limits and symphotonic states in free-mass gravitational-wave antennae", Phys. Lett. **A246** (1998) 485

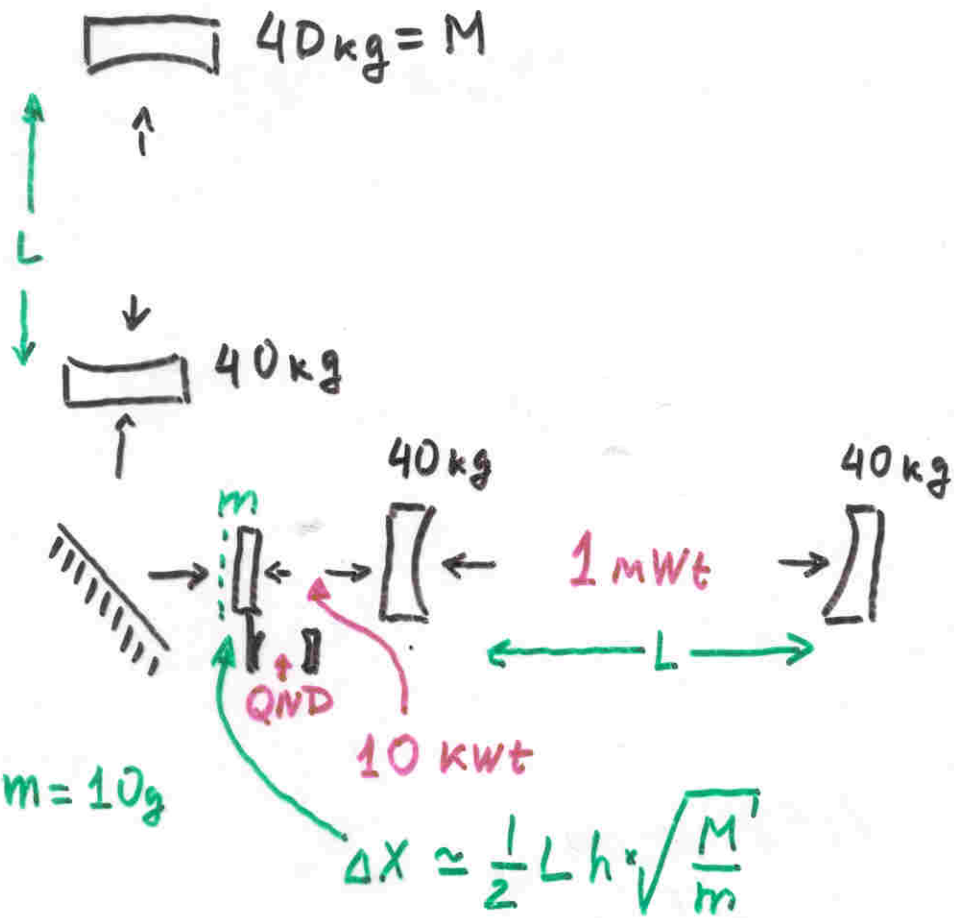
F.Ya.Khalili, "The 'optical lever' intracavity readout scheme for gravitational-wave antennae", Phys. Lett. **A298** (2002) 308

Advantages: Non-classical quantum state of the optical field is generated automatically during the measurement process. The only fundamental limitation in sensitivity is due to internal losses in the optical cavities:

$$\frac{h}{h_{\rm SQL}} \approx \sqrt{\frac{\mathcal{E}_{\rm SQL}}{\mathcal{E}}\frac{1}{\Omega\tau^*}} \approx \sqrt{10^{-3}\times\frac{\mathcal{E}_{\rm SQL}}{\mathcal{E}}}$$

Disadvantages: Sensitivity of this class of methods depends crucially on the local meter's design and achievable sensitivity, which is unknown yet.

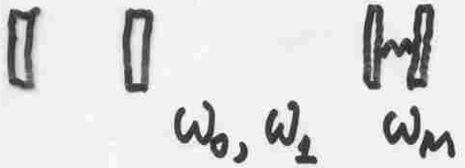
Our opinion: This way looks as the most promising, but it require extensive R&D, both experimental and theoretical, devoted to the local meter.



THE „OPTICAL LEVER" INTRACAVITY SCHEME

F. YA. KHALILI, PHYS. LETT. A <u>298</u>, 308 (2002)

1. PARAMETRIC OSCILLATORY INSTABILITY (POI)



$$\hbar\omega_0 = \hbar\omega_1 + \hbar\omega_M$$

THRESHOLD $\Rightarrow R_0(\mathcal{E}, Q_M, Q_{OPT}, \Delta\omega)$

$$\Delta\omega = \omega_0 - \omega_1 - \omega_M$$

FOR LIGO II, IF $\Delta\omega = 0$, THEN $R_0 \cong 2 \times 10^{+5}$!

(V. BRAGINSKY, S. STRIGIN, S. VYATCHANIN, PH. LETT A, 305, 111 (2002))

THE "REMEDIES": TRANQUALISERS OF DIFERENT TYPES:

V. BRAGINSKY, S. VYATCHANIN, PH. LETT. A 293, 228, (2002)

V. MITROFANOV, N. STYAZHKINA, K. TOKMAKOV, PH. LETT A, 278, 25 (2000)

2. 1/f NOISES IN ALL COMPONENTS HAVE TO BE IDENTFIED AND MEASURED BEFORE FINAL DESIGN IS CHOOSEN.

3. THE TRAP?

$$\frac{(\mathcal{E}_{OPT})_{SQL} = 40\,J = 4 \times 10^{+8}\,erg}{(\Delta\mathcal{E}_{mech})_{SQL} = \frac{m\Omega^2(\Delta x)^2_{SQL}}{2} = \frac{10^{+4}\cdot 10^{+6}\cdot 10^{-34}}{2} = 5\cdot 10^{-25}} \simeq 10^{-33}!$$