Review of QND schemes for ET

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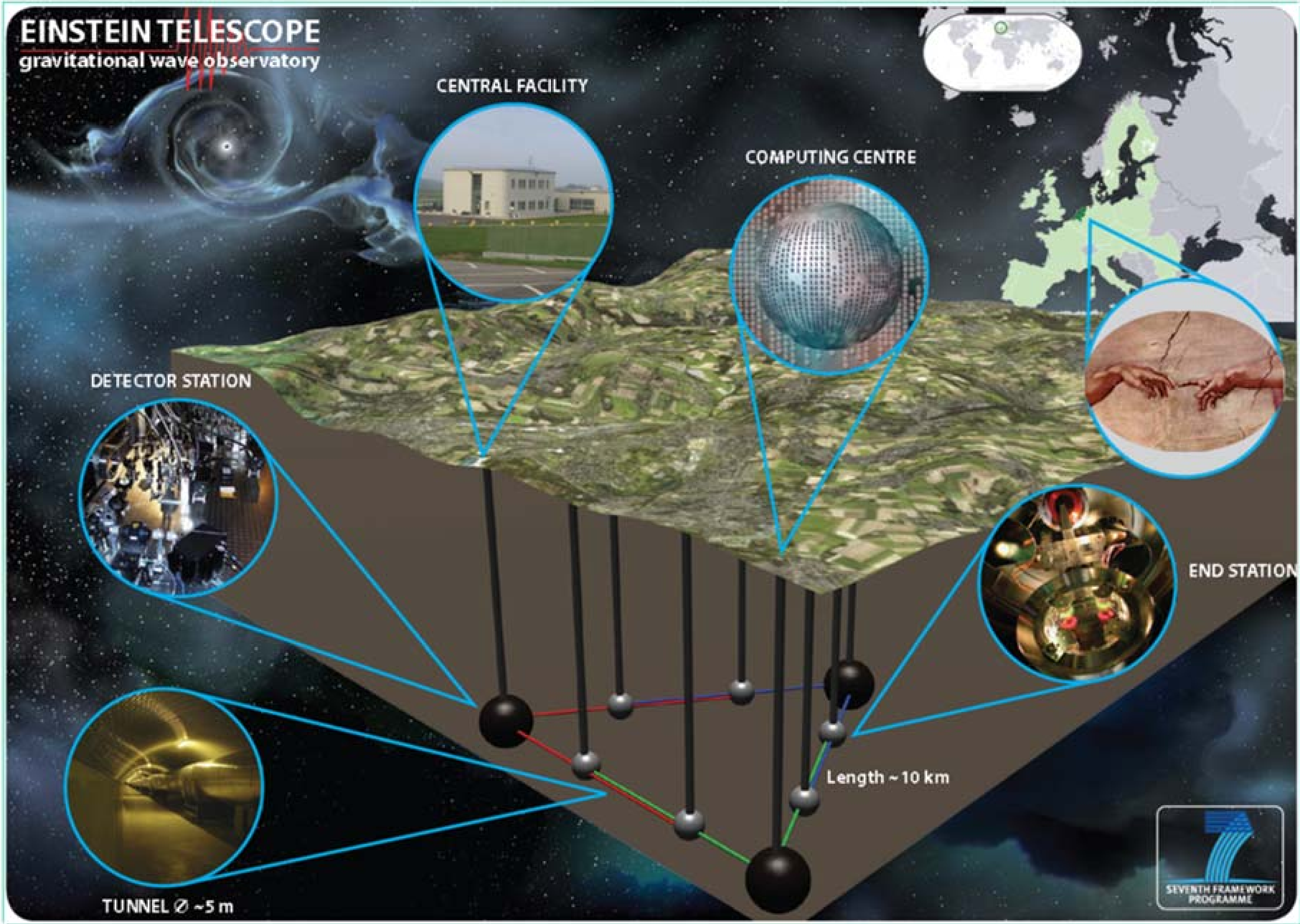
[3]California Institute of Technology

ET: Einstein Telecope

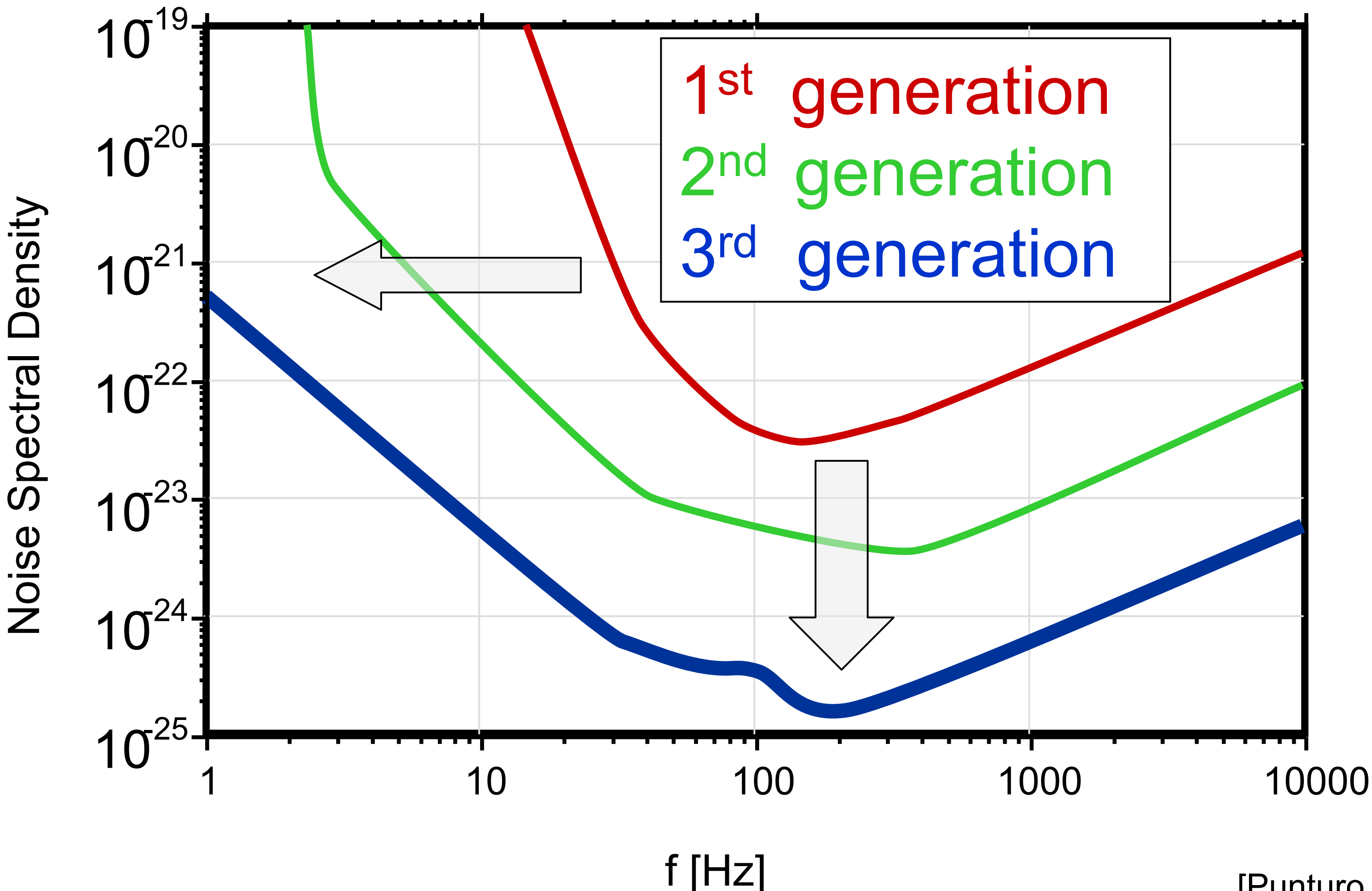
- A European 3rd generation gravitational-wave observatory
- Conceptual design study funded by the European Union


EINSTEIN TELESCOPE
gravitational wave observatory
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
END STATION
Length ~ 10 km
TUNNEL ∅ ~5 m
SEVENTH FRAMEWORK PROGRAMME

ET working groups

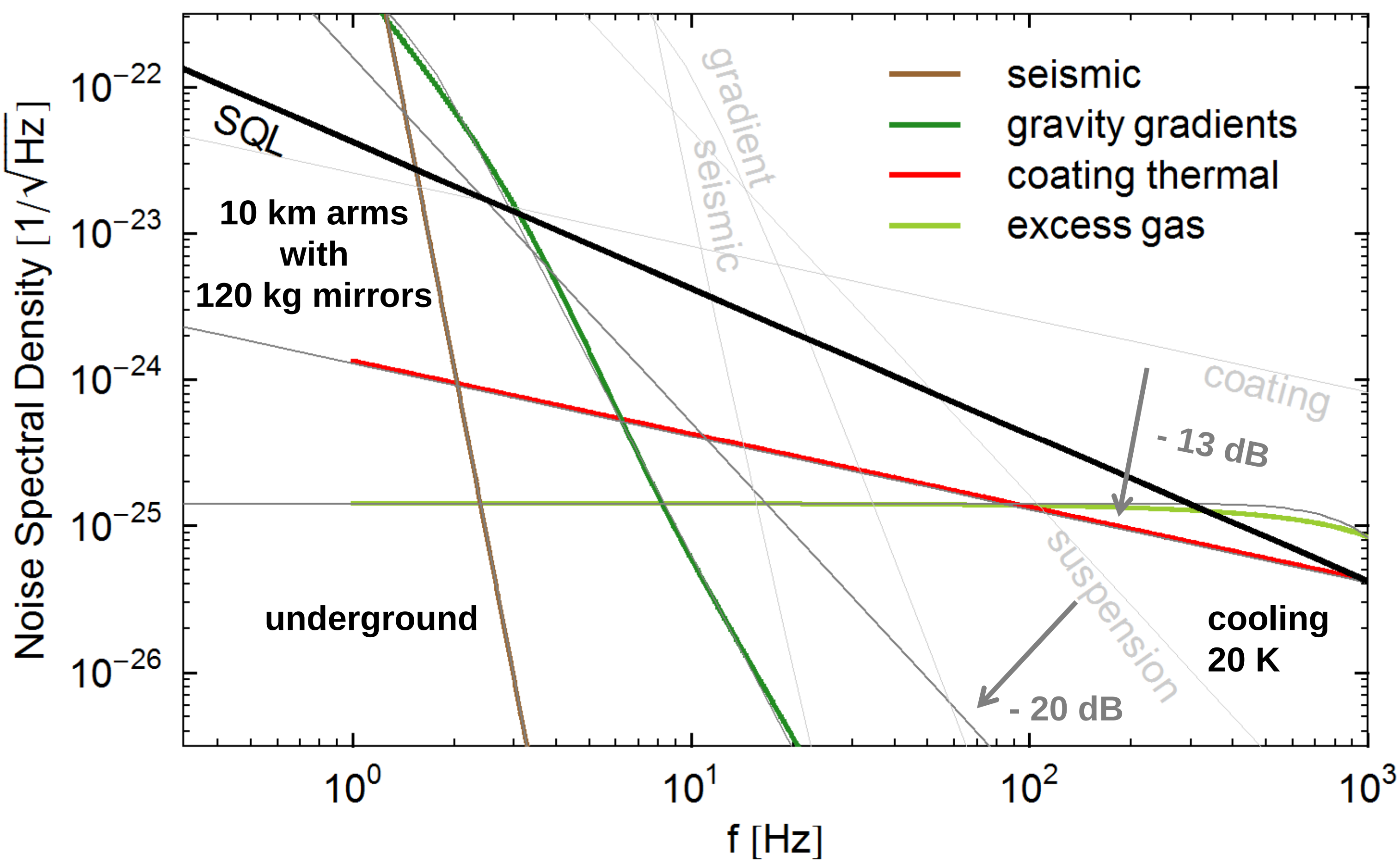
- WP1: site location and characteristics, seimic studies
- WP2: thermal noise reduction, suspension design and technologies
- WP3: detector topology and geometry, quantum noise reduction
- WP4: detection capabilities requirements and astrophysics potentialities

First idea about possible noise curve for ET



[Punturo, 2008]

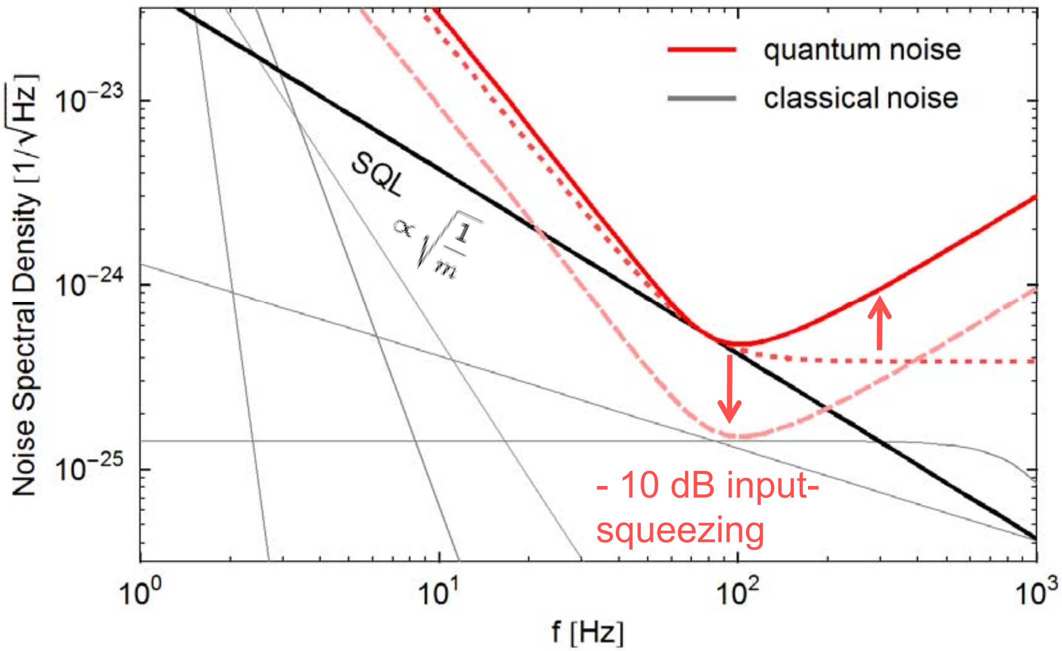
ET potential classical noise performance

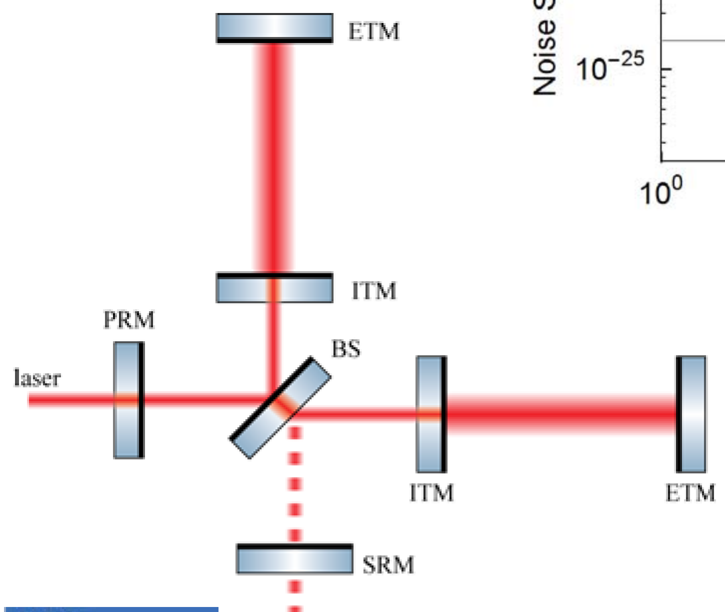


[Hild, 2009]

Non-detuned SR Michelson interferometer

finite cavity bandwidth → quantum noise rises with f over bandwidth at high frequencies

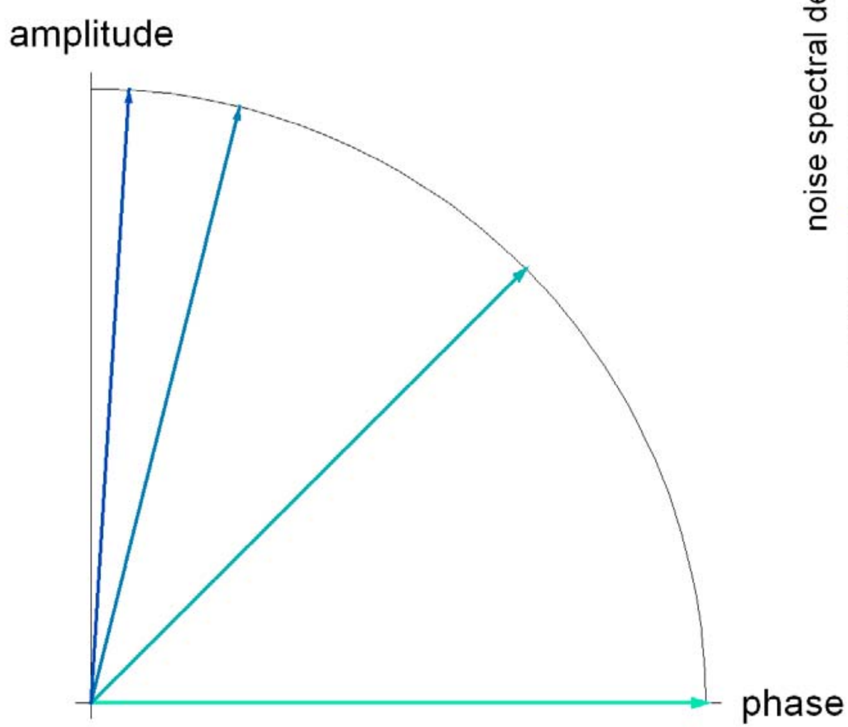


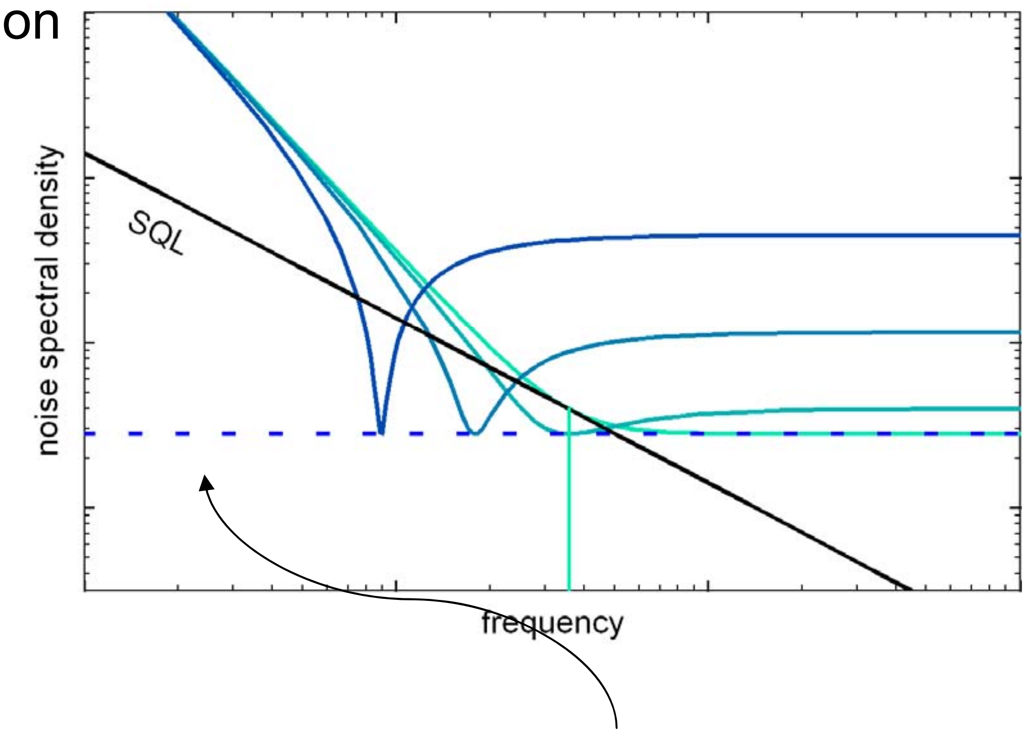


3 MW circulating optical power in an effective 100 Hz cavity
→ quantum noise touches SQL at ≈ 78 Hz

QND technique: variational output

balanced homodyne detection at frequency-independent quadrature angle





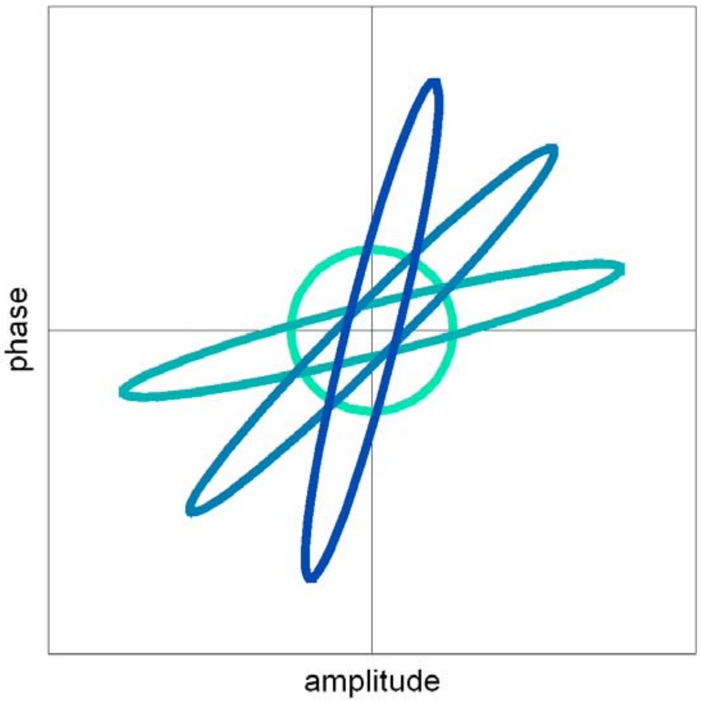
variational output with frequency-dependent quadrature angle

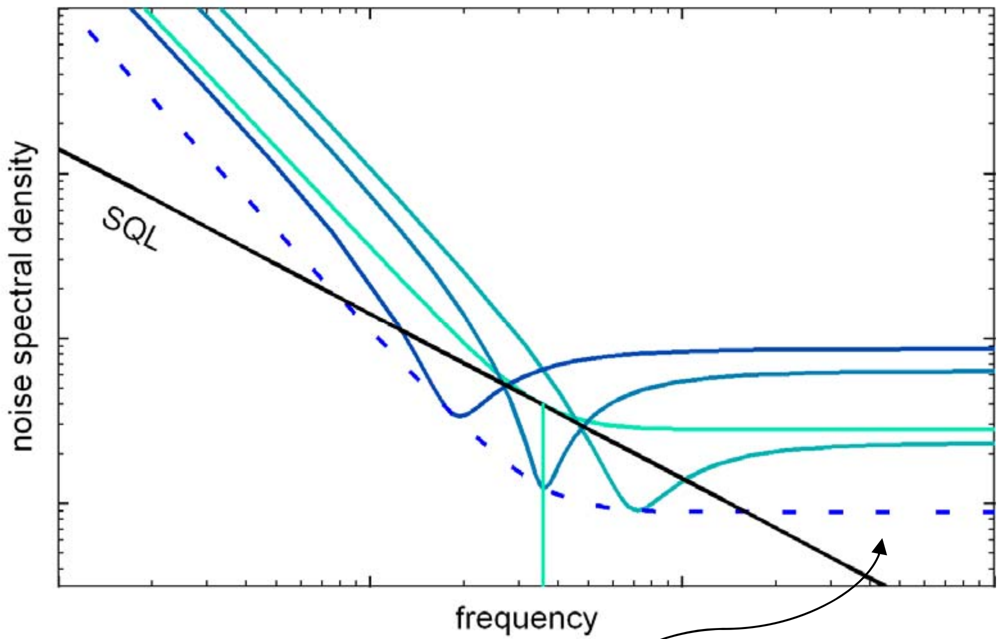
[Kimble et al, 2001]

[Harms et al, 2003]

QND technique: input-squeezing

squeezed input at frequency-independent quadrature angle



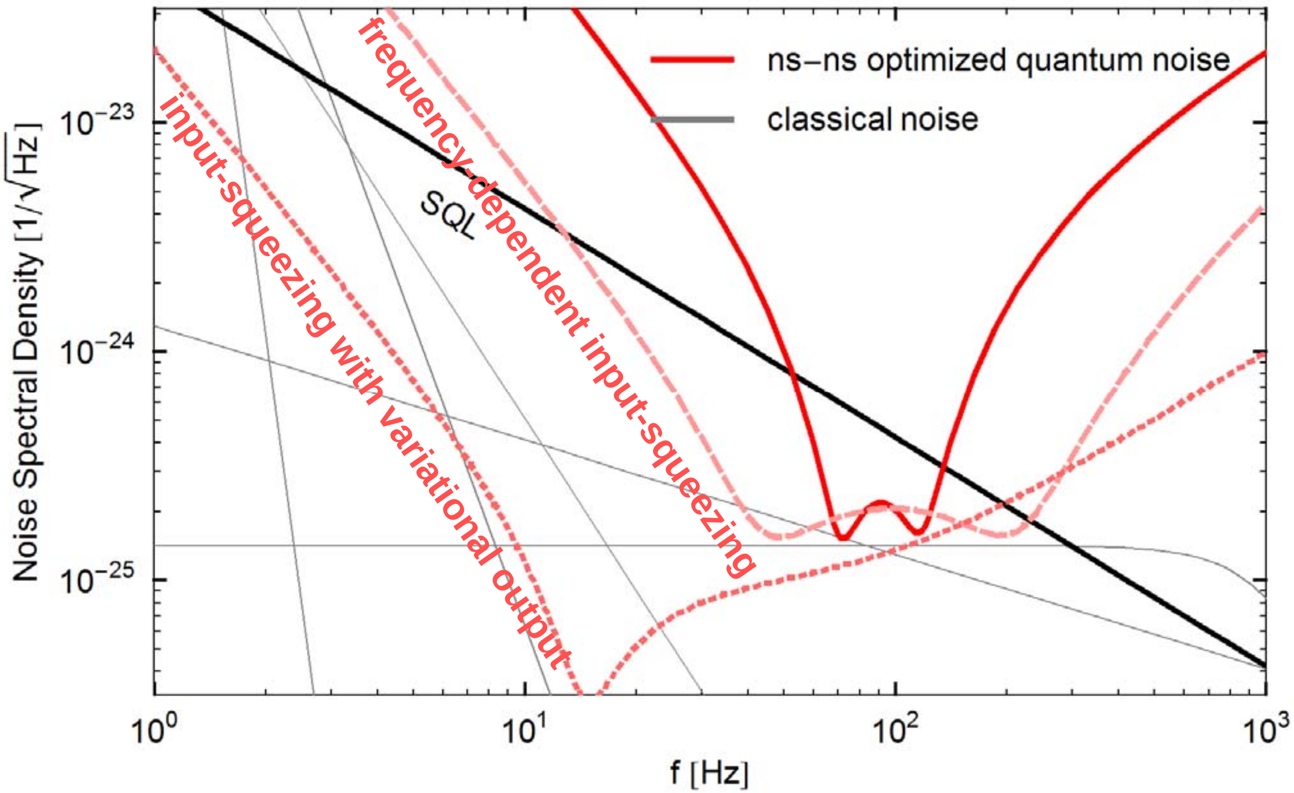


squeezed input with frequency-dependent quadrature angle

[Kimble et al, 2001]

[Buonanno & Chen, 2004]

SR Michelson optimized towards NS-NS



binary range:

1500 Mpc

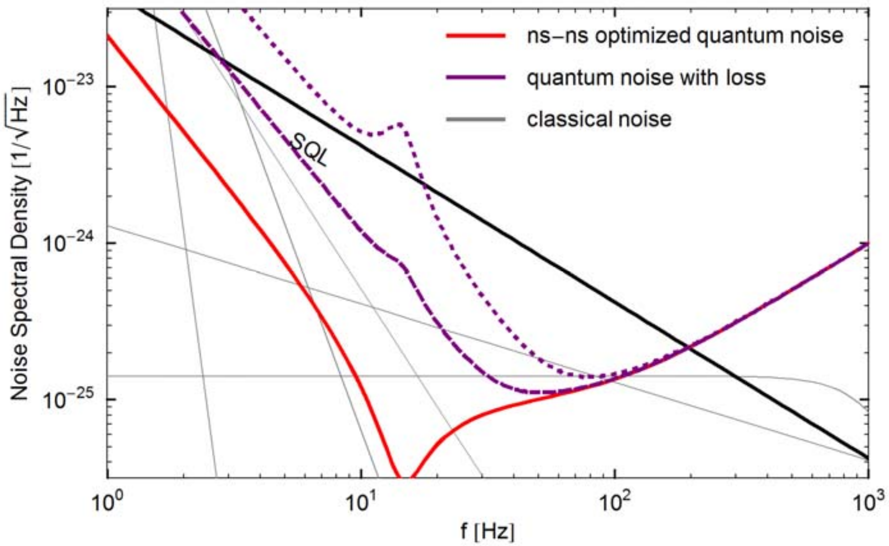
3000 Mpc

5000 Mpc

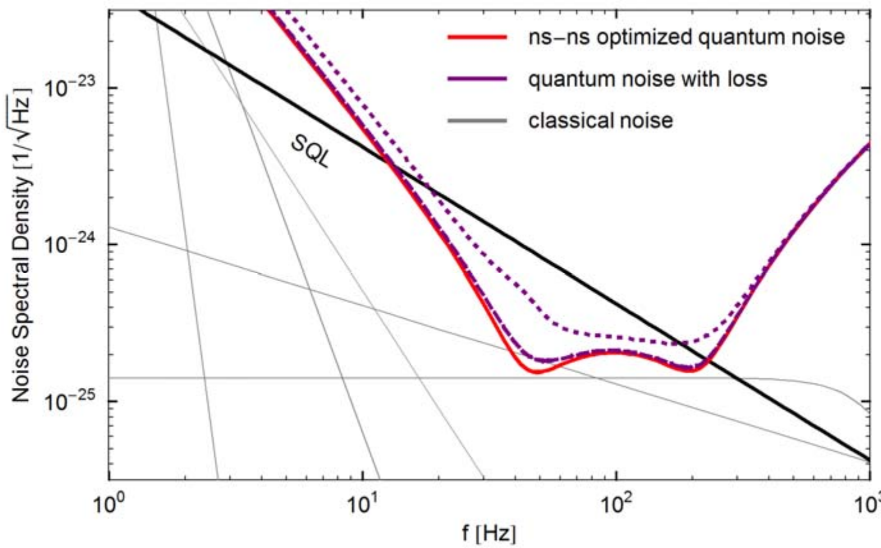
	effective detuning	effective bandwidth	homodyne angle	squeezing angle
no input-squeezing	136 Hz	8 Hz	2 π / 3	-
10 dB input-squeezing	208 Hz	60 Hz	0.44 π	frequency-dependent
10 dB input-squeezing	4 Hz	92 Hz	frequency-dependent	0

SR Michelson with optical loss

quantum noise spectrum highly sensitive to loss in the filter cavities



input-squeezing with variational output with 20 ppm loss in two 10 km (1 km) long filter cavities

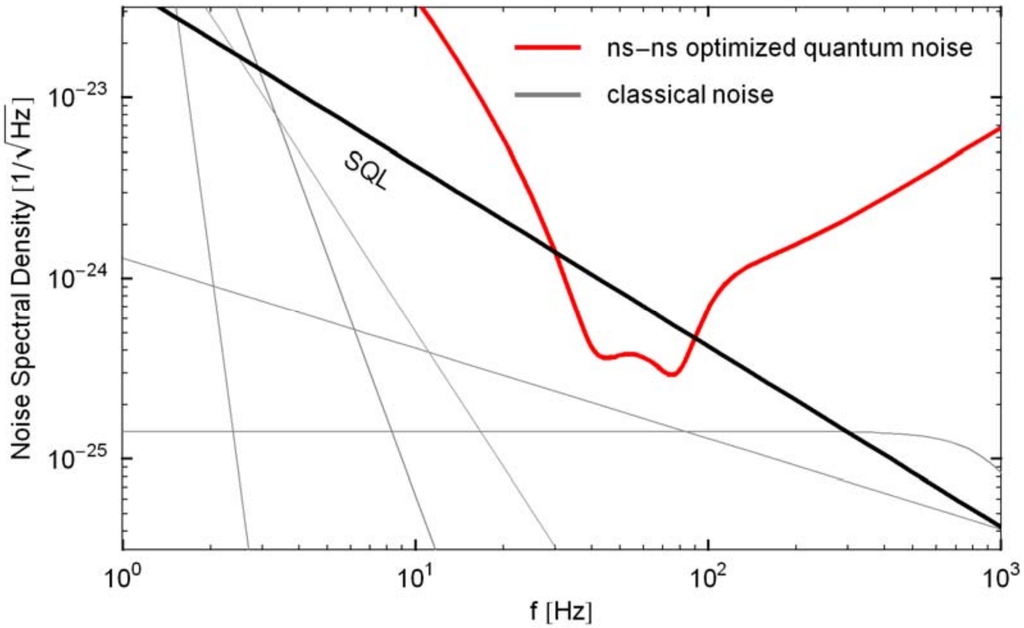


frequency-dependent input-squeezing with 300 ppm loss in two 10 km (1 km) long filter cavities

DOS optimized towards NS-NS

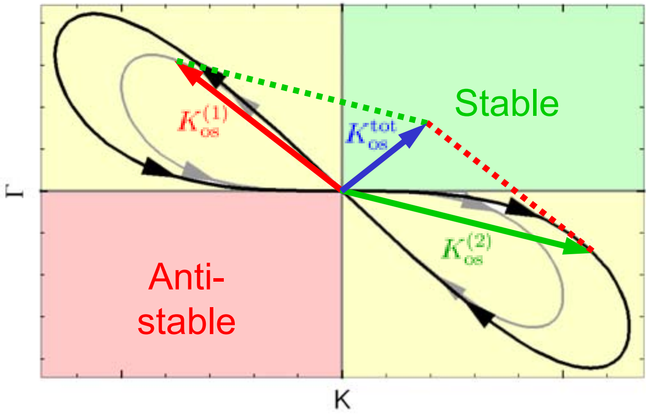
secondary laser establishes additional optical anti-spring

→ double optical spring scheme



binary range:

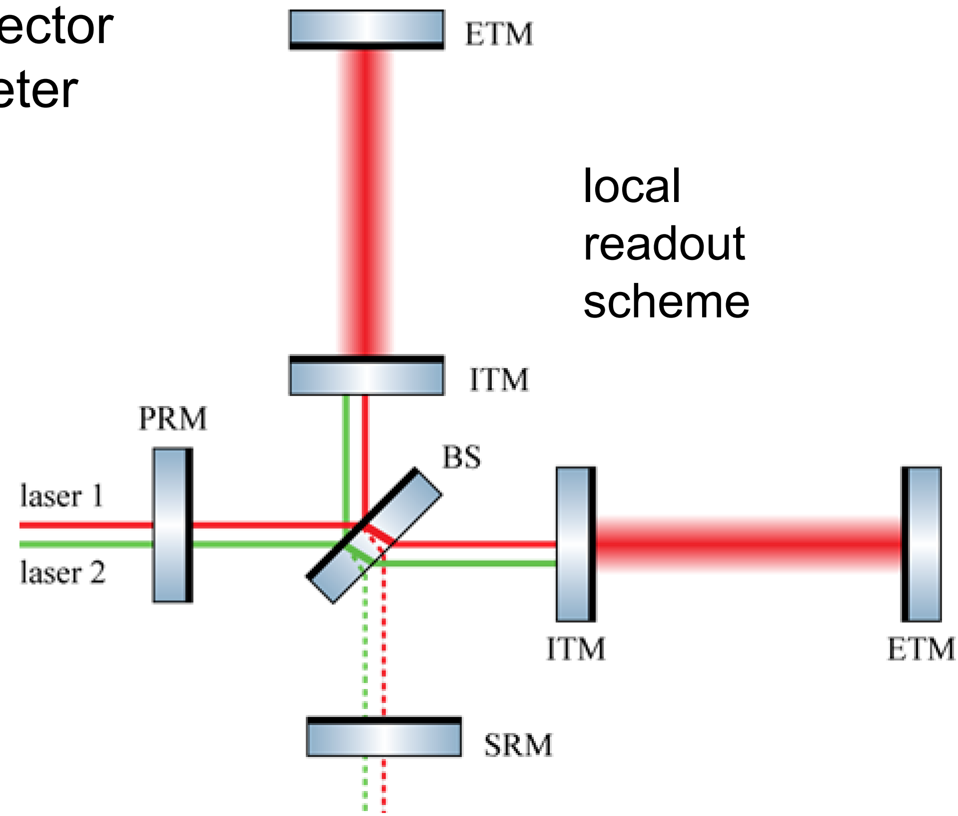
1800 Mpc



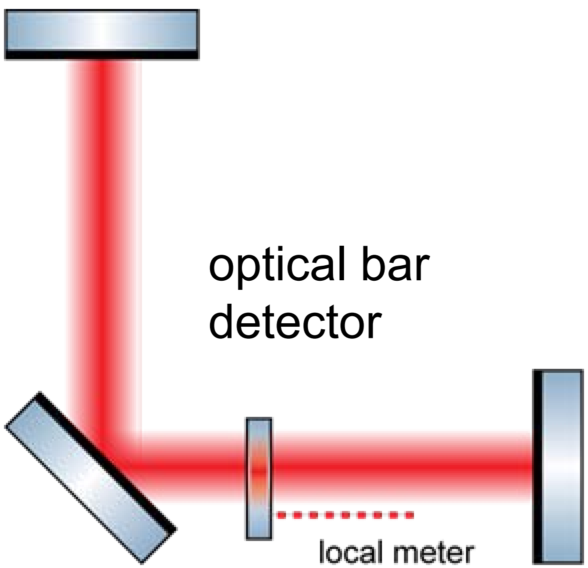
1.5 MW circulating optical power in each optical spring

Optical bar / local readout scheme

combination of optical bar detector
and SR Michelson interferometer
→ local readout scheme

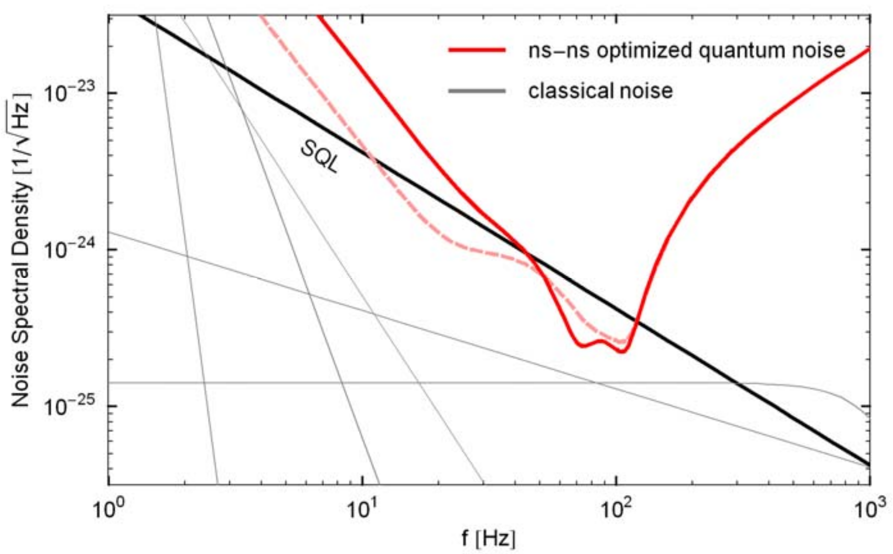


[Rehbein, Müller-Ebhardt et al., 2007]



[Braginsky, Gorodetsky & Khalili, 1997]

Local readout optimized towards NS-NS

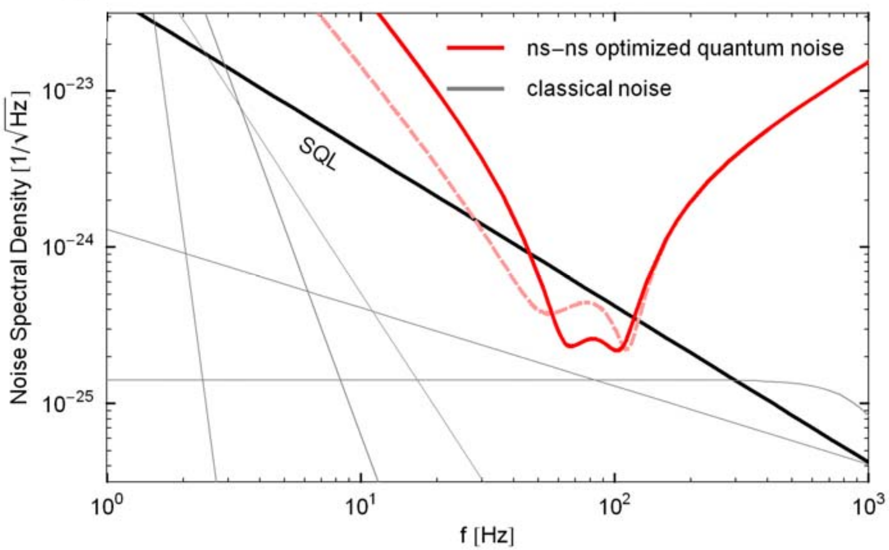


binary range:

1700 Mpc

local meter with 1 kW optical power

local meter with 10 kW optical power



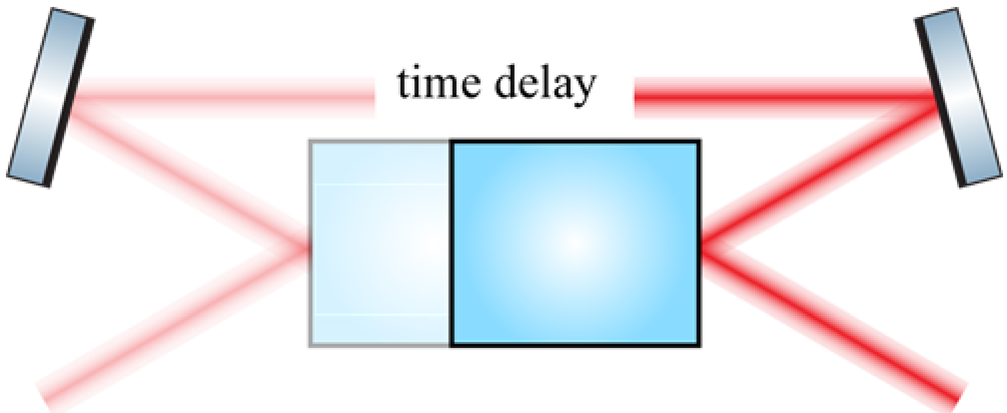
binary range:

1800 Mpc

Speed meter idea

measure position difference after time delay → measure speed

[Braginsky & Khalili, 1990]



$$x(t+\tau) - x(t) = \dot{x}(t)\,\tau + \ldots$$

conserved momentum usually proportional to speed → real QND?

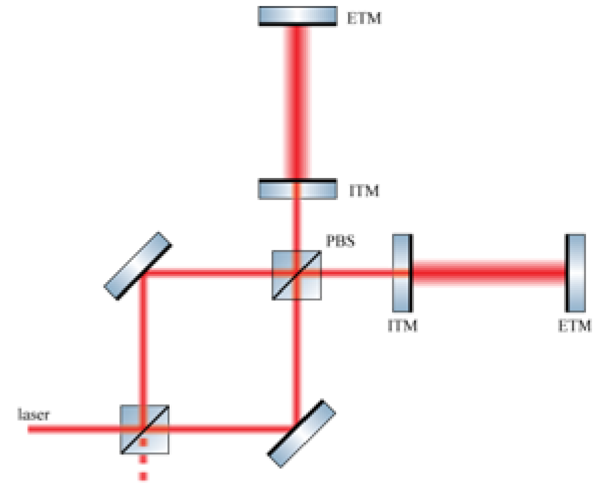
no: because the coupling to speed changes conserved momentum

[Khalili, 2002]

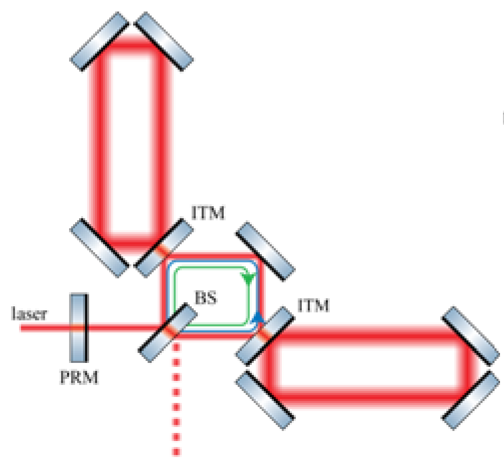
Speed meter realizations

many different optical realizations proposed:

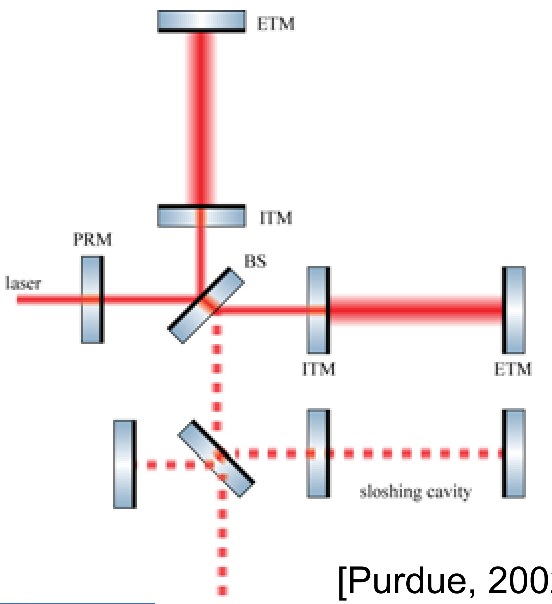
- Michelson topology with sloshing cavity
- zero area Sagnac topology with ring cavities
- using polarizing optics



[Danilishin, 2004]

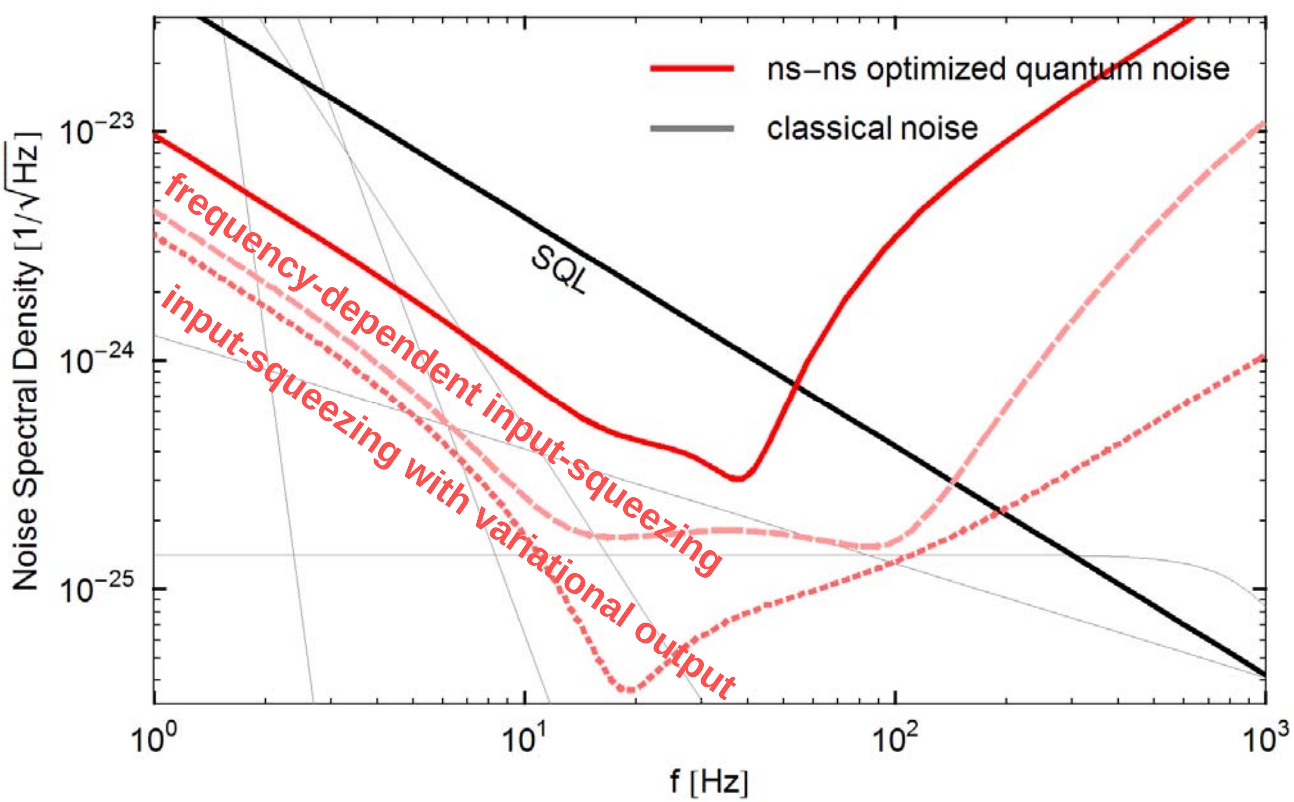


[Chen, 2003]



[Purdue, 2002]

SR Sagnac optimized towards NS-NS



binary range:

2800 Mpc

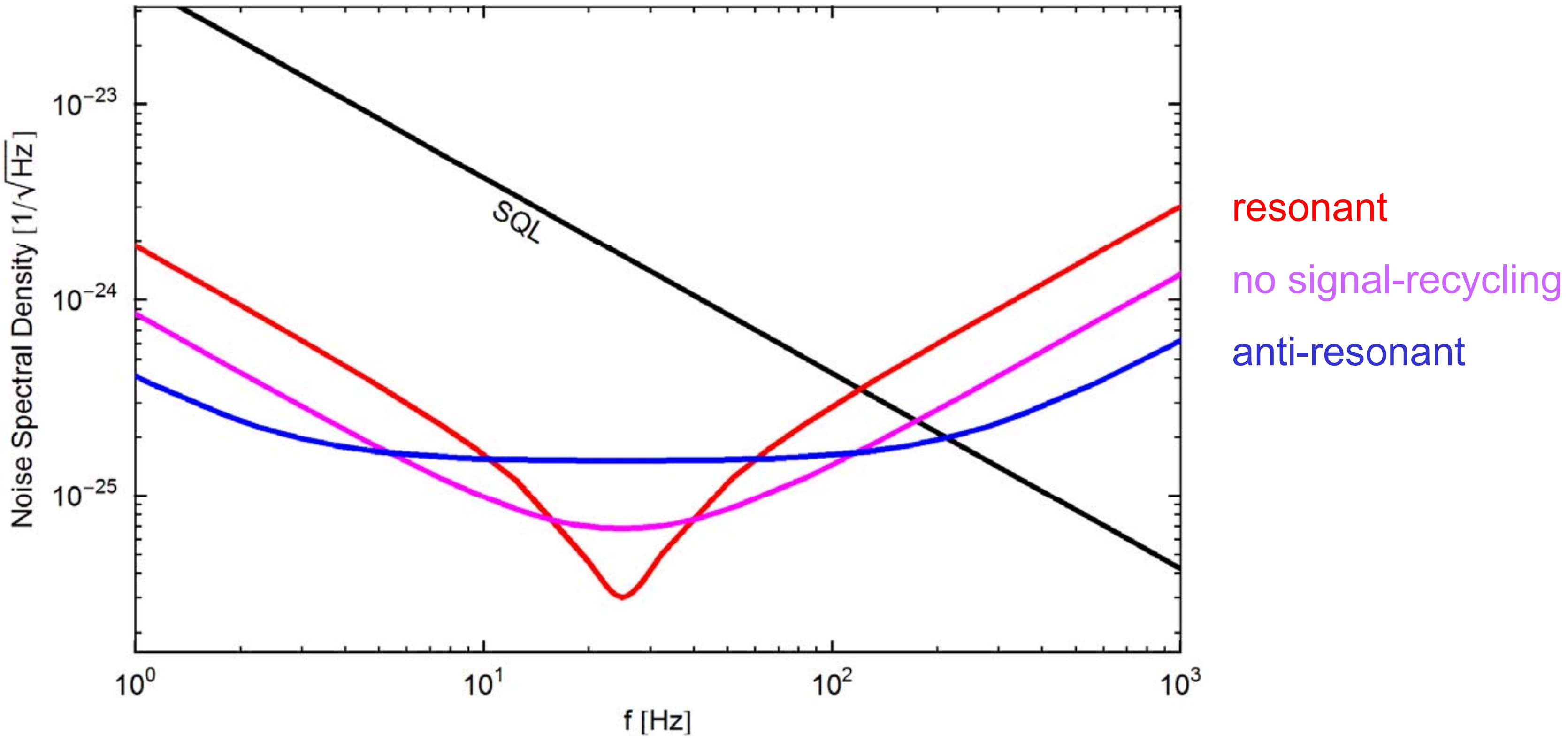
4500 Mpc

5000 Mpc

	bandwidth	effective detuning	effective bandwidth	homodyne angle	squeezing angle
no input-squeezing	50 Hz	42 Hz	30 Hz	0.475 π	-
10 dB input-squeezing	75 Hz	95 Hz	54 Hz	0.475 π	frequency-dependent
10 dB input-squeezing	25 Hz	0.5 Hz	9 Hz	frequency-dependent	0

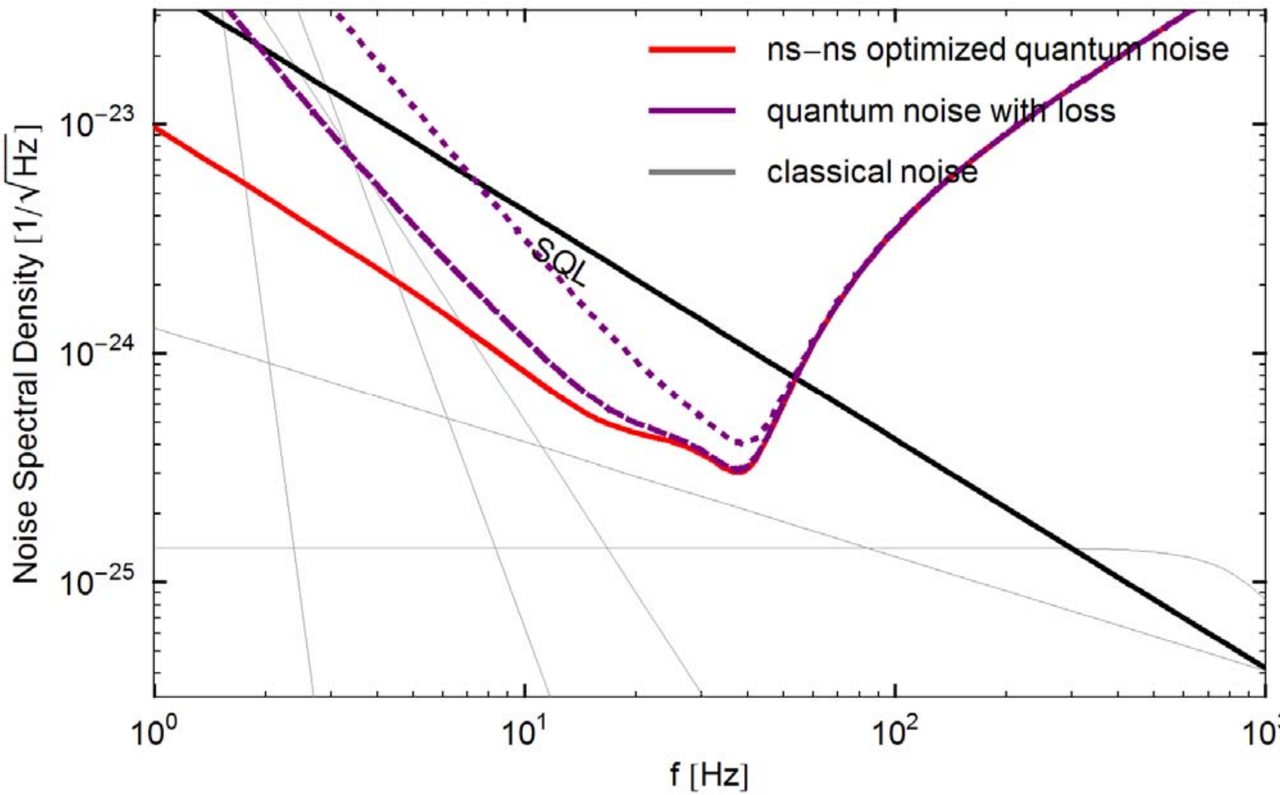
Non-detuned Sagnac with variational output

quantum noise of a non-detuned Sagnac interferometer with input-squeezing and variational output very easy to model



SR Sagnac with optical loss

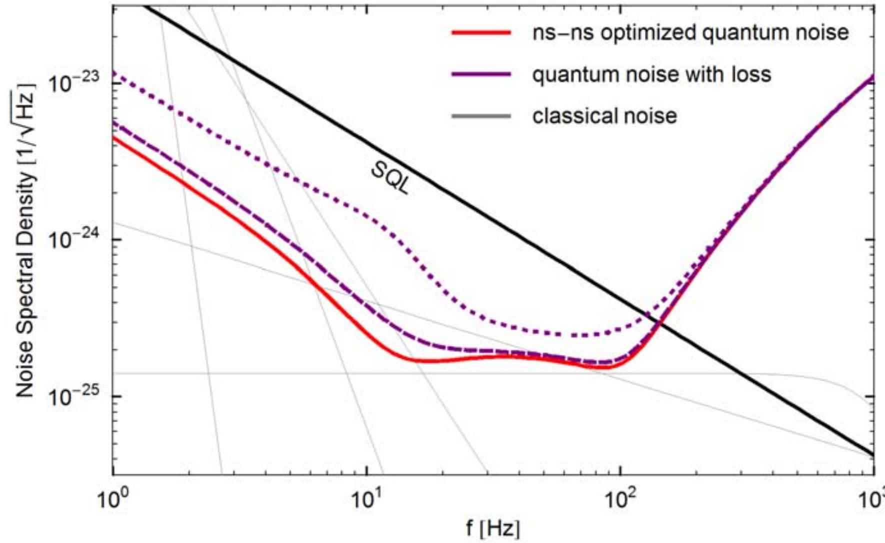
quantum noise at low frequencies sensitive to optical loss in the ring cavities



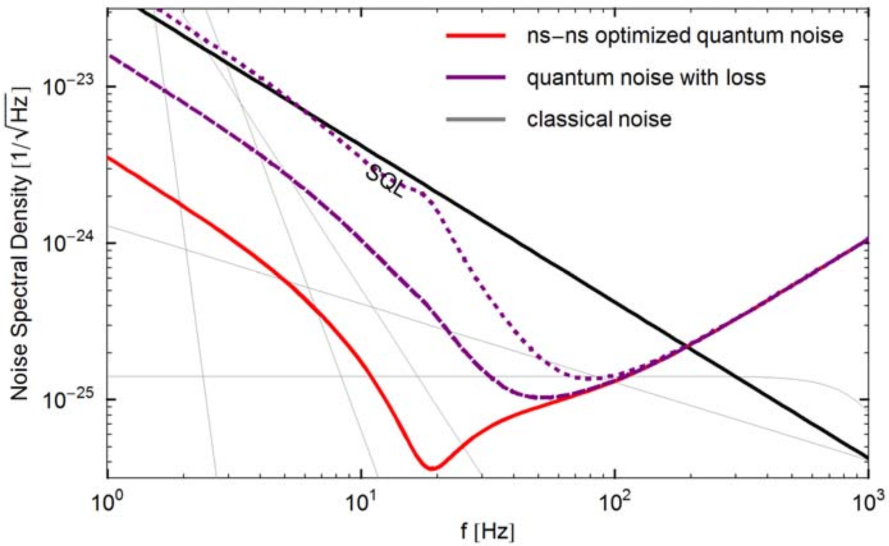
20 ppm (300 ppm) loss of a single mirror in the ring cavities

SR Sagnac with optical loss

quantum noise spectrum highly sensitive to loss in the filter cavities



frequency-dependent input-squeezing with 300 ppm loss in two 10 km (1 km) long filter cavities



input-squeezing with variational output with 20 ppm loss in two 10 km (1 km) long filter cavities

Outlook

- more rigorous classical noise estimation, e.g. for suspension thermal noise (WP2)
- true classical noise estimation for different optical configurations
- different optimization method, i.e. for astrophysical sources at higher frequencies (WP4)
- more detailed investigation of quantum noise considering optical loss
- investigate new QND schemes