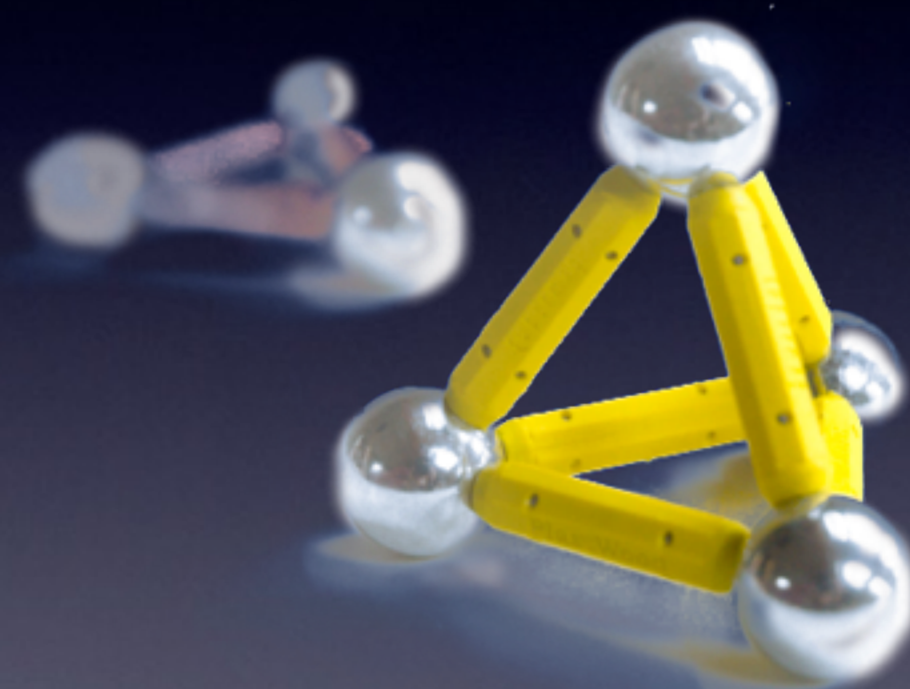
Einstein Telescope: The Interferometer Design

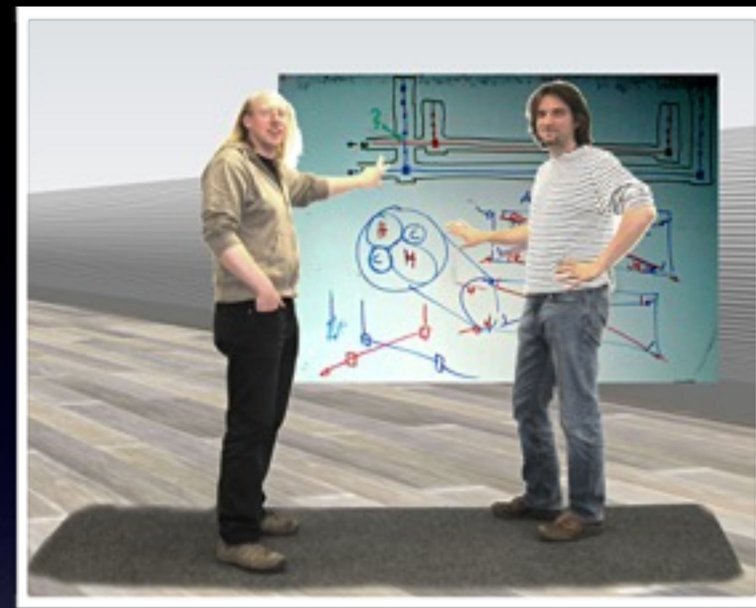


Andreas Freise

19.05.2015, GWADW Alaska

LIGO-G1500677

Overview



- ET Interferometers
- Why a triangle?
- Why a xylophone?
- More detailed documents:
  - Construction of the ET optical layout (GWADW, 2010), DCC G1500666
  - Einstein Telescope: The Interferometer Design Sensitivity Studies (ET workshop 2010) DCC G1500667
  - ET design study document, 2011(http://www.et-gw.eu/)

Assignment for ET interferometers

Target: Produce a reference design (no technical design) for a broadband interferometer with a tenfold sensitivity improvement versus the current state of the art (advanced detectors).

Boundary conditions are important and are not always entirely based on science.

Impact of possible global networks on the ET interferometer design

Functioning of ET in various conceivable scenarios of a global network:

- advanced detectors (Advanced LIGO, Advanced Virgo, LGCT, LIGO South, ...)
- advanced detectors plus third generation dectors in USA, Japan, …
- third generation detectors

Conclusion: different performance in different constellation, however, no influence on the optical design of the single site!

Any new input since 2010?

[A. Vicere in A. Freise et.al: `Optical Detector Topology for Third-Generation Gravitational Wave Observatories', *General Relativity and Gravitation*, **2010**]

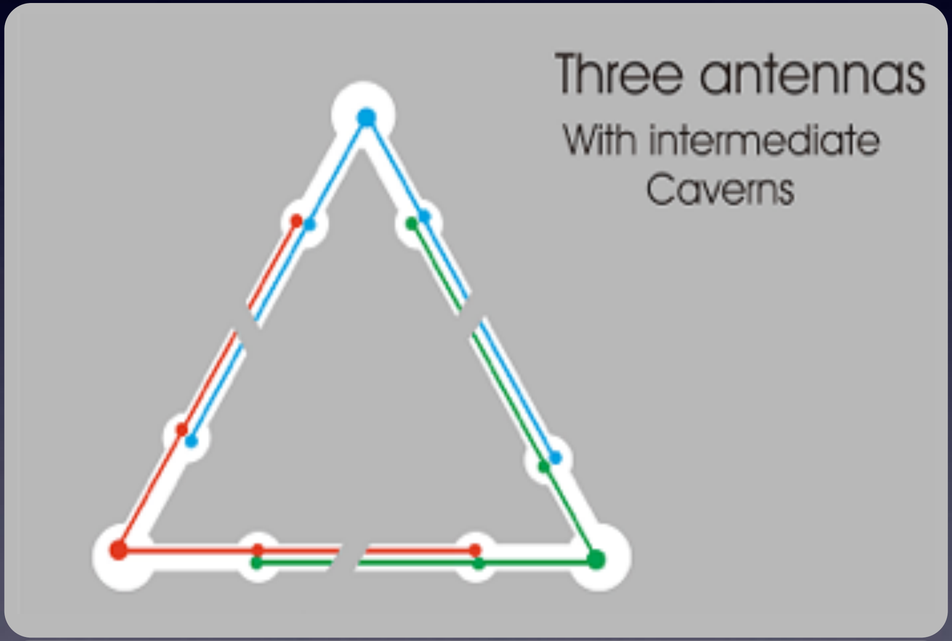
The Triangle

A detailed analysis of the how the triangle makes efficient use of `tunnel' length was presented by Ruediger in 1985.

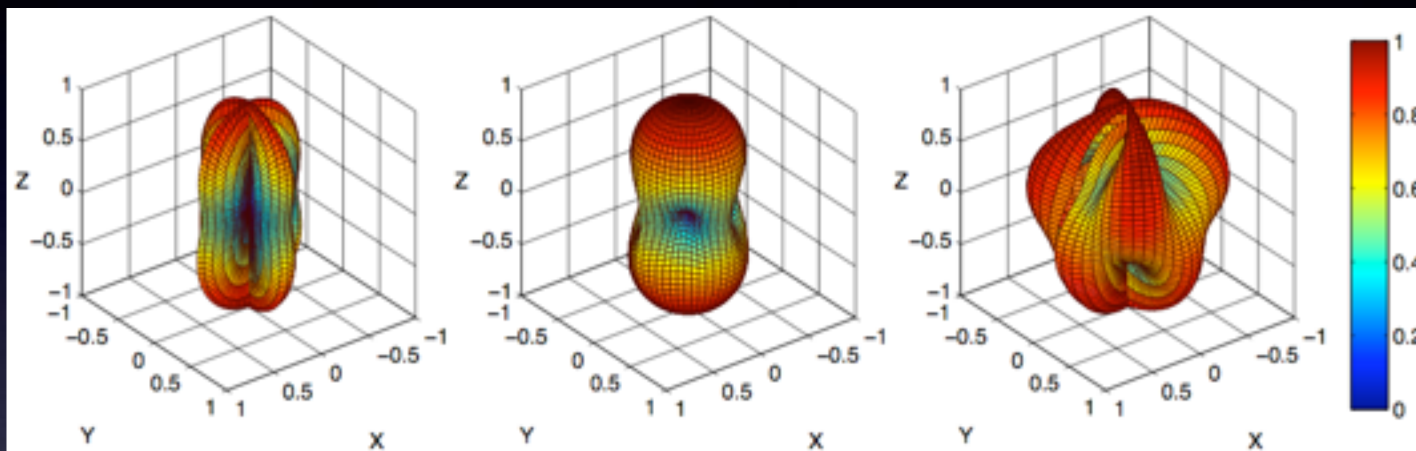
[W. Winkler et al.: Plans for a large gravitational wave antenna in Germany. Fourth Marcel Grossmann Meeting on General Relativity, **1986**, 621-630]

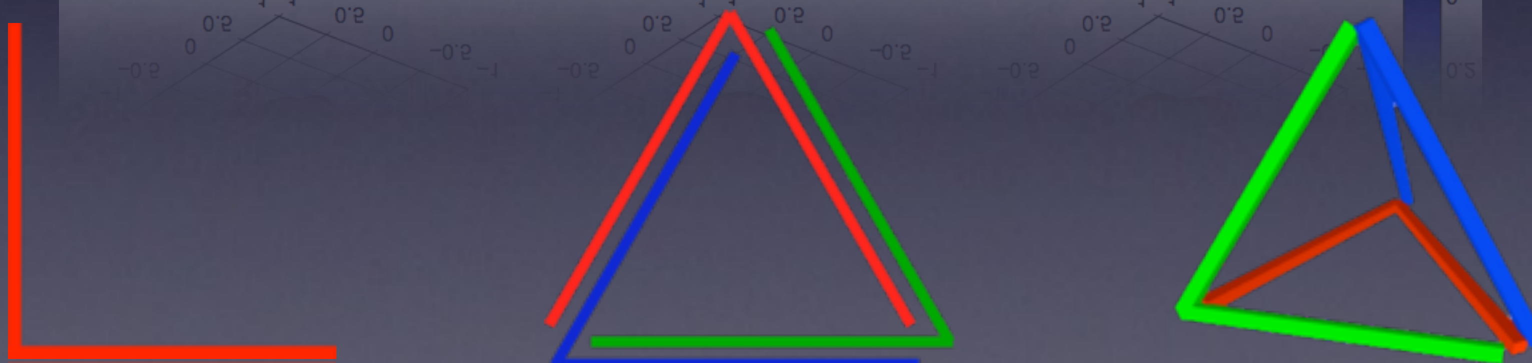
To my knowledge, no other early documentation on this idea exist! This design was reviewed for ET.

[A. Freise et. al.: Triple Michelson interferometer for a third-generation gravitational wave detector, Classical and Quantum Gravity, 2009, 26]

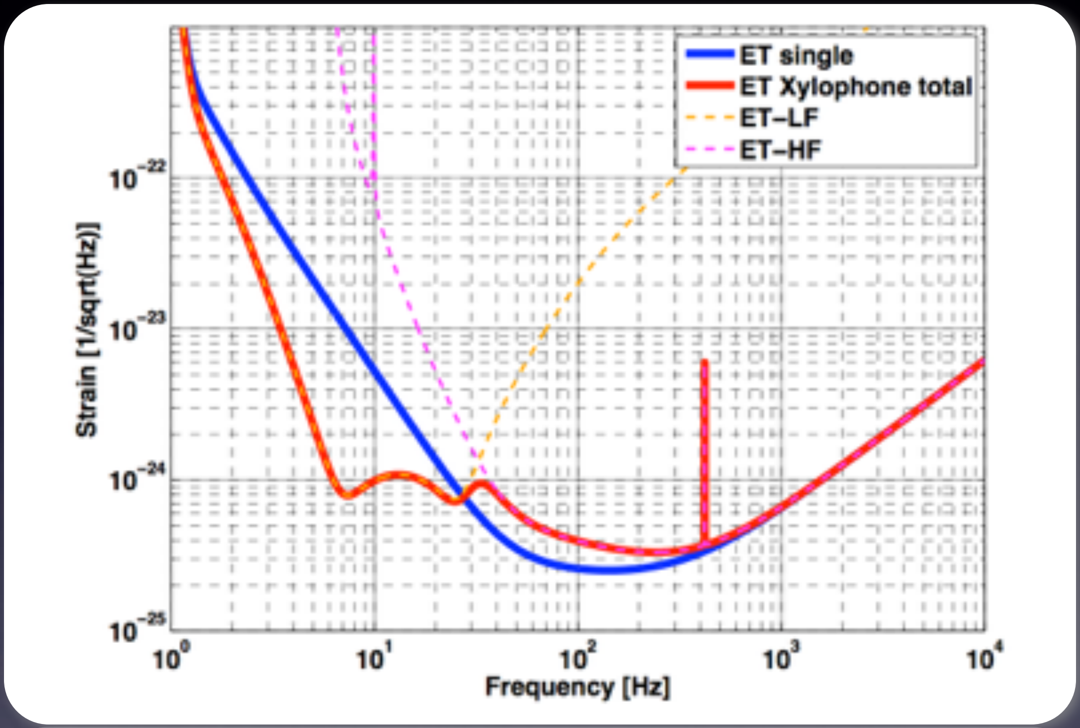


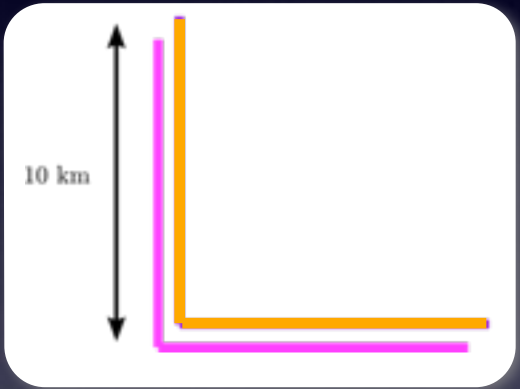
Beyond the Triangle!





The Xylophone





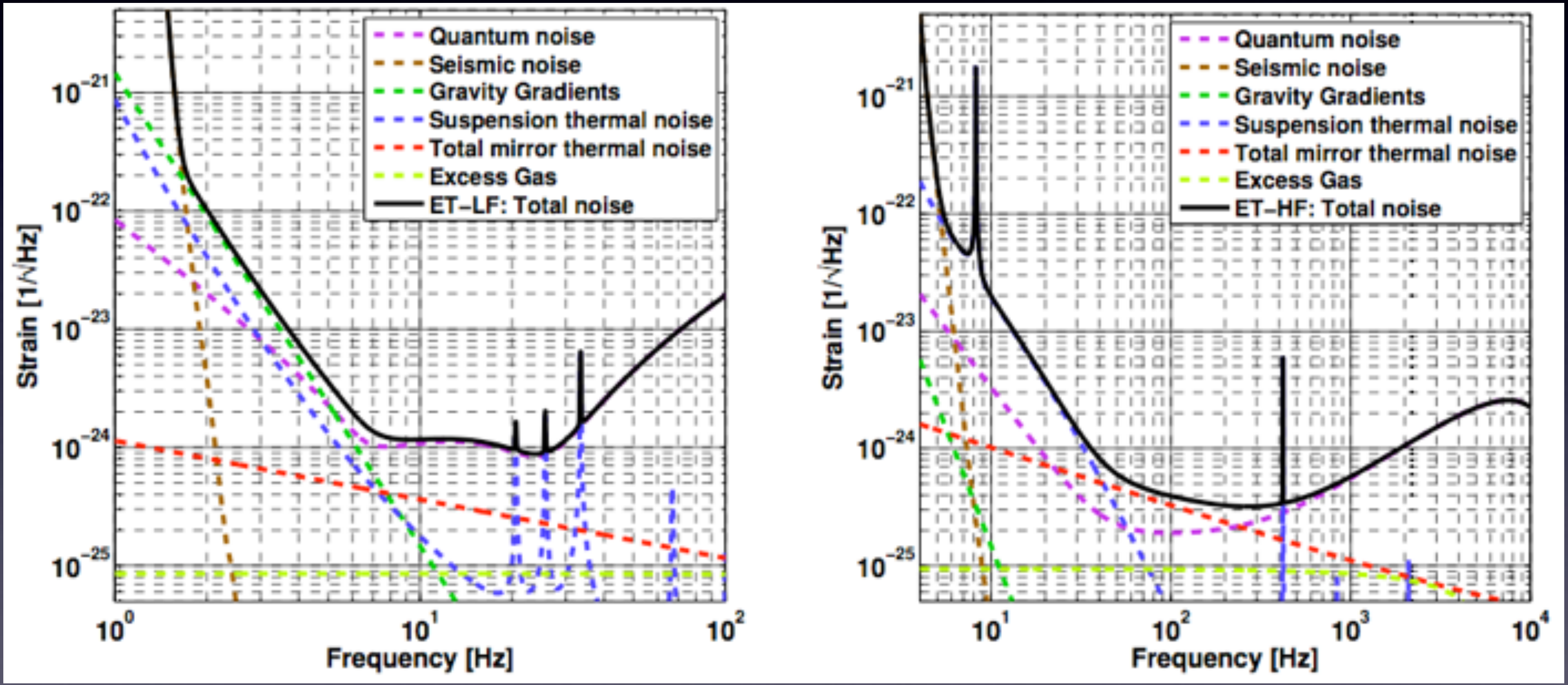
- Low power (no thermal effects), cooled, long suspensions
- High power, squeezing, LG modes, room temperature, `normal' suspensions

[S Hild et al: A xylophone configuration for a third-generation gravitational wave detector, Classical and Quantum Gravity, **2010**, 27]

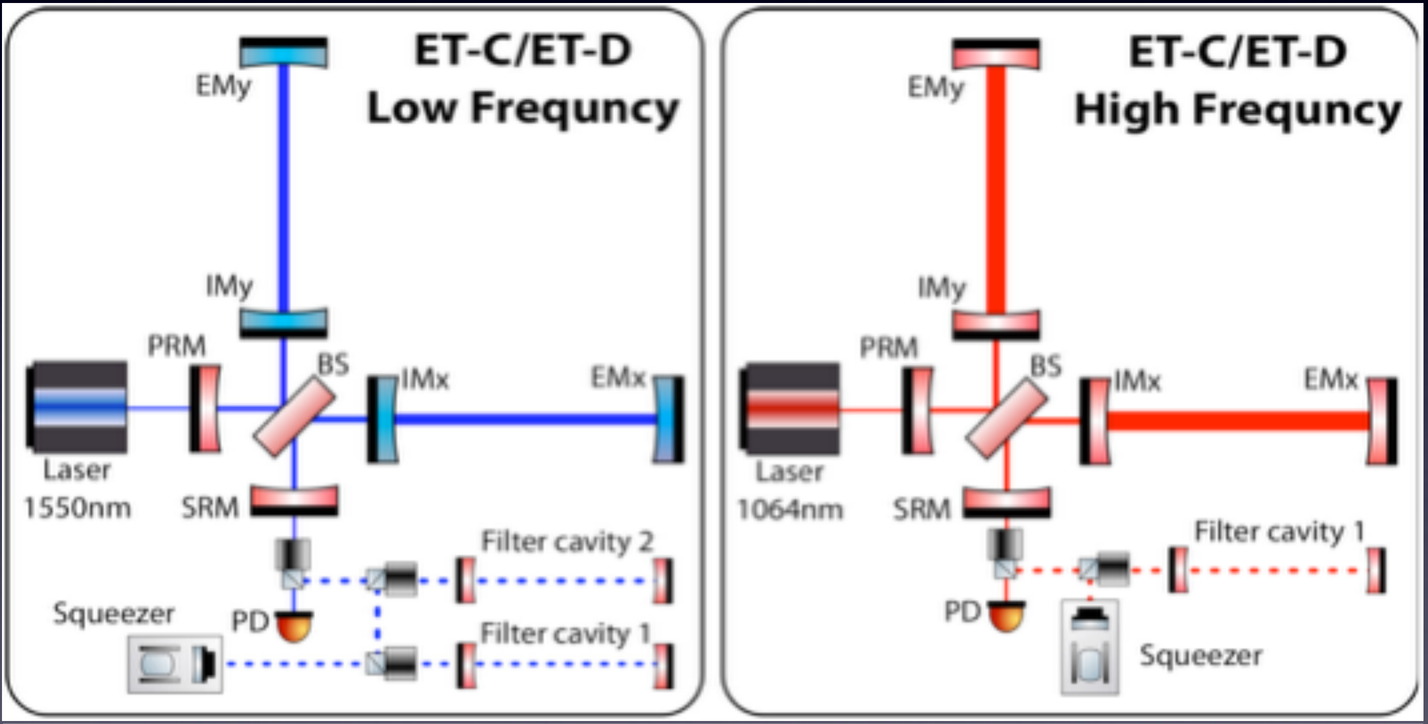
ET D Parameters

Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	Fused Silica	Silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ TBD
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	none

ET D Sensitivity



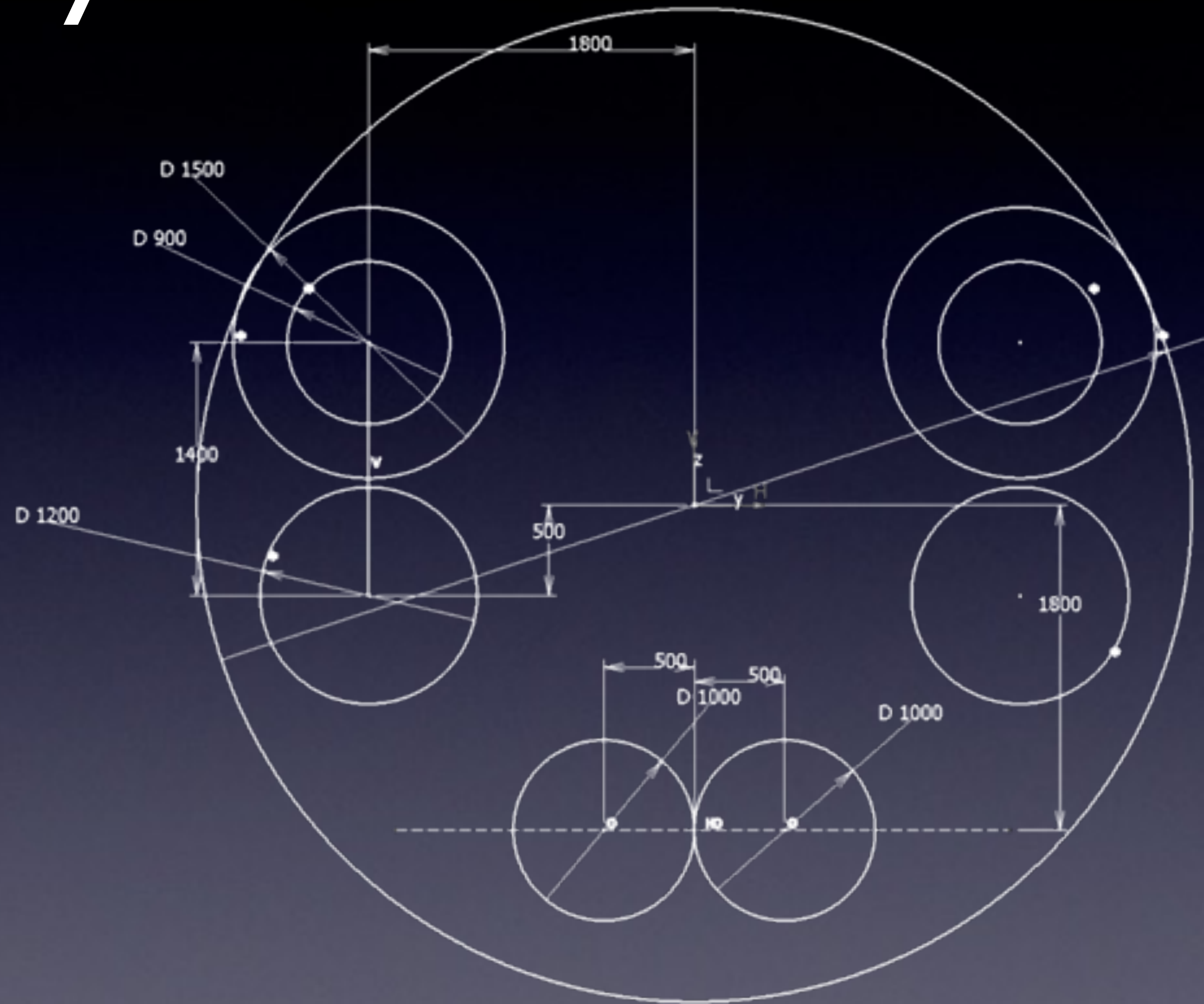
Double Optical Layout



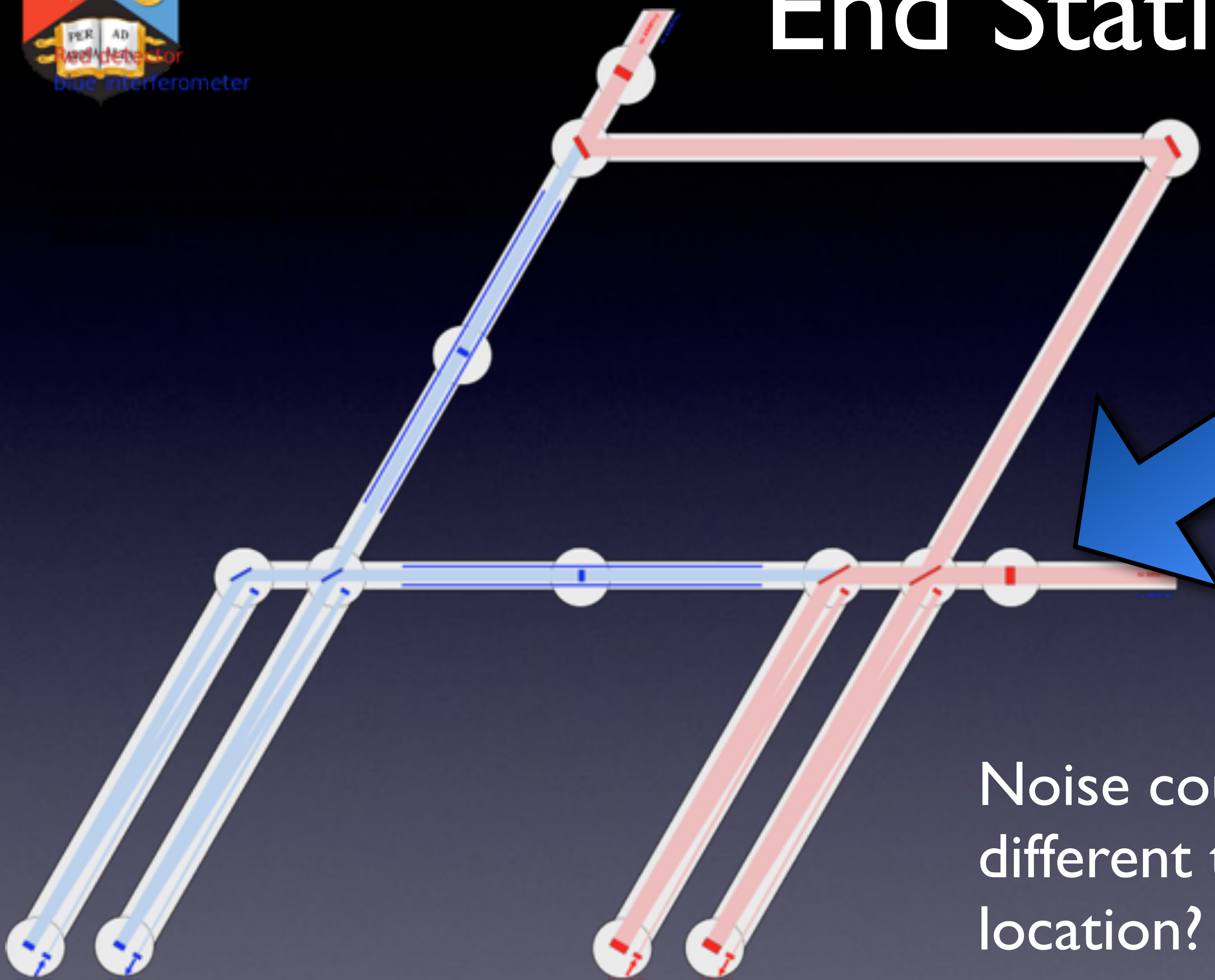
[Hild et al 2010]

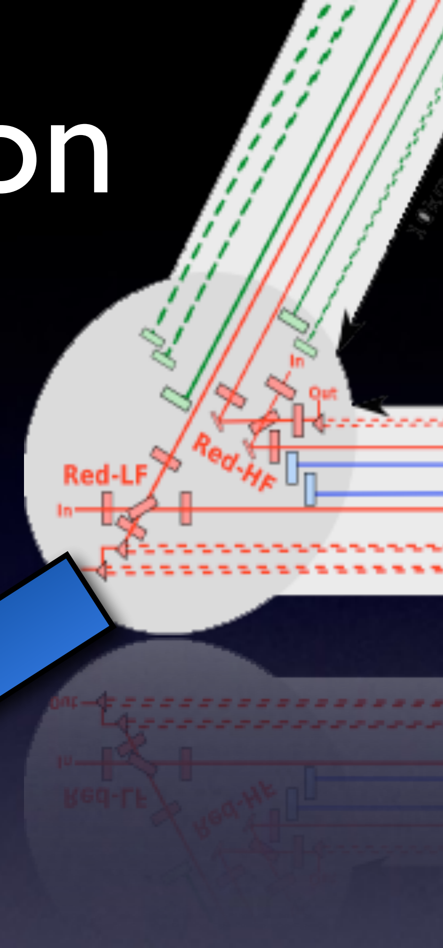
Tube Layout

A draft design of the entire vacuum system with stacked individual tubes for each beam.



End Station





Noise coupling for different types of co-location?

Sagnac vs. Michelson

- Sagnac shows better quantum noise suppression
- However, it has one main practical problem, the ring-cavities in the arms
- All high-precision expertise so far is with the Michelson
- Michelson with RSE/SR and squeezing and filter cavities has been chosen as the reference design

New experimental results in progress!

Some Summary

- Infrastructure for long term use (observatory)
- Broadband detector
- Each detector consists of two (more?) interferometers
- Can fix high-power cold-temperature problem
- Otherwise LF interferometer uses state of the art as does the HF interferometer
- LF interferometer: potential for new QN technique

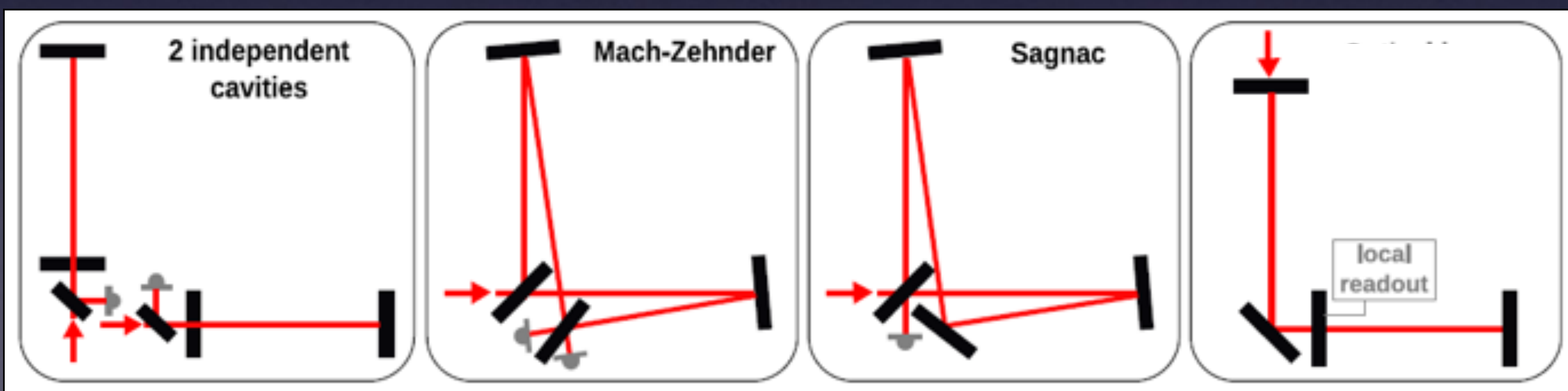
...end

Interferometer Topology: Defined by Quantum Noise Reduction

Several QNR topologies seem feasible:

- Micheslon with SR, variational output, squeezing
- Sagnac or Mach Zehnder Interferometer with SR, …
- Optical bars, optical levers, double optical spring, …

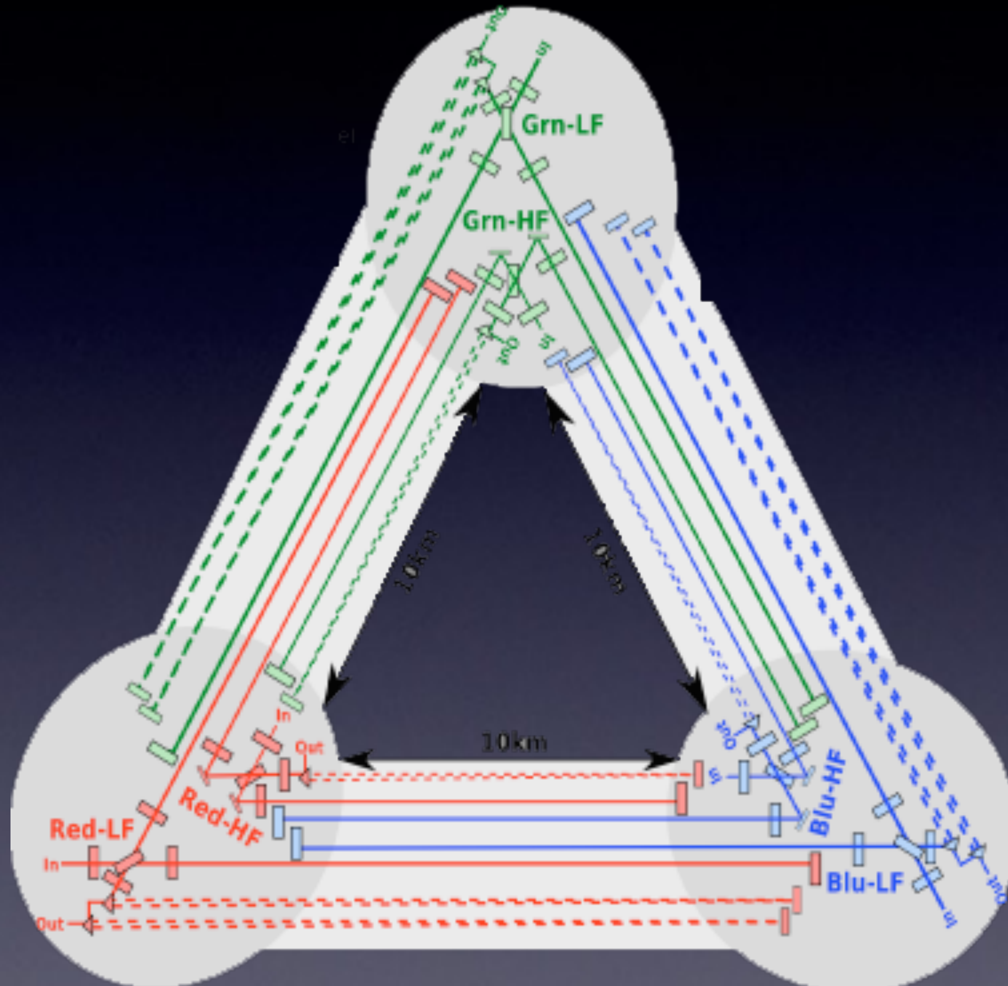
All can be build using the L-shape form factor!



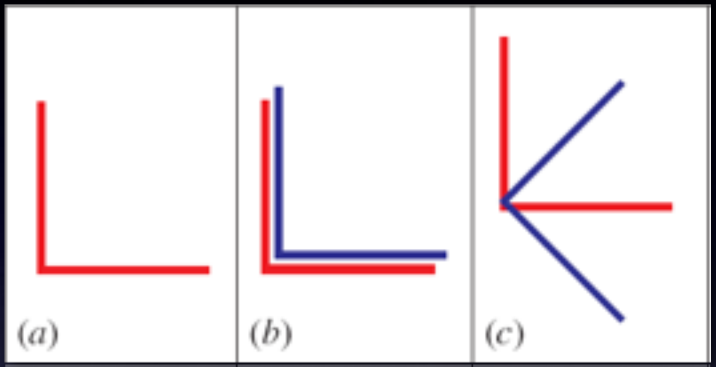
Draft Optical Layout

Simple drawing of an optical layout consisting of:

- 3 independent detectors
- 2 interferometers per detector (LF+HF)
- 3 filter cavities per detector
- 21 long suspensions
- 45 short suspensions
- 12 cryogenic mirrors



Multiple Interferometers

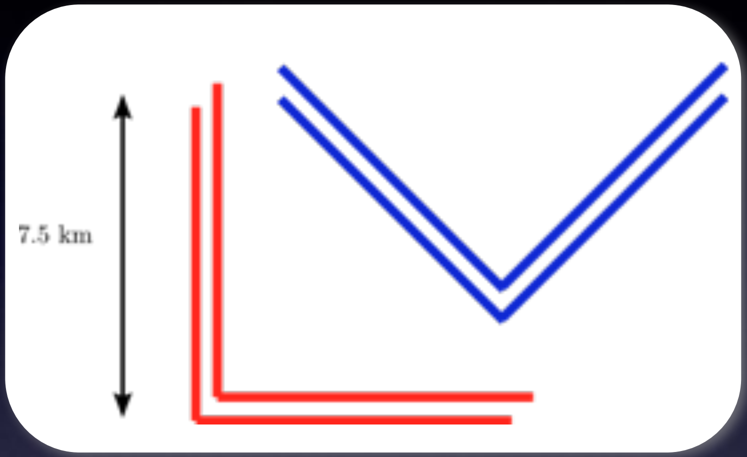


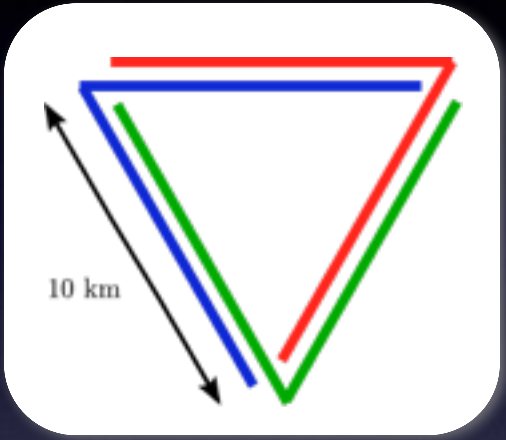
a. The L-shape provides the best form for a differential measurement of quadrupole waves

b. Two parallel interferometers provide redundancy (nullstream creation, operation during maintenance and upgrades)

c. Two interferometers under 45 degrees can resolve both polarisations

Multiple Interferometers





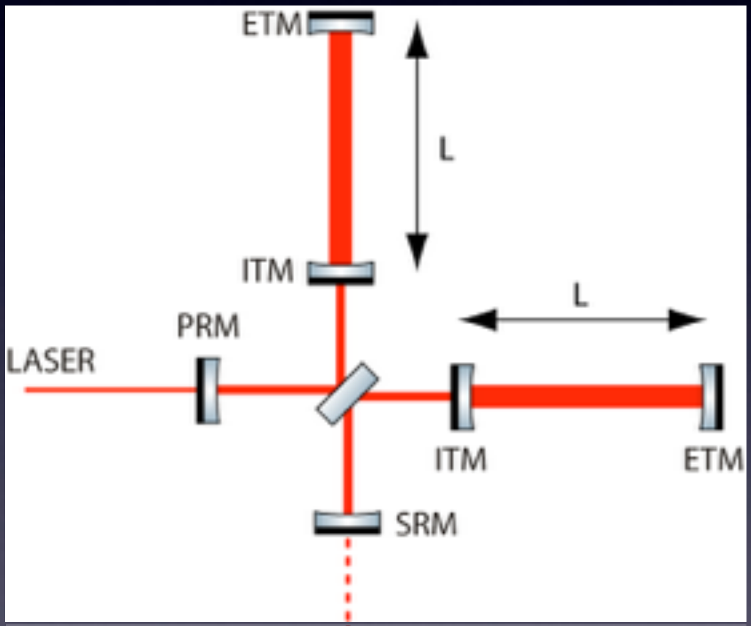
$$h(t) = F_+(t)h_+(t) + F_\times(t)h_\times(t)$$ [P Jaranowski et al, Phys Rev D 58 1998]

Both solutions have an integrated tunnel length of 30 km, they can resolve both GW polarisations, feature redundant interferometers and have equivalent sensitivity.

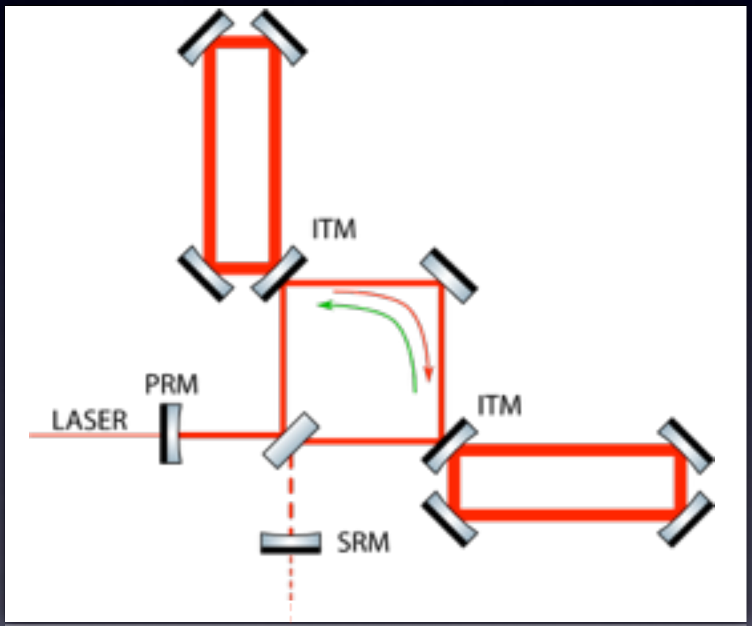
The triangle reduces the number of end stations and the enclosed area!

Sagnac vs. Michelson

RSE

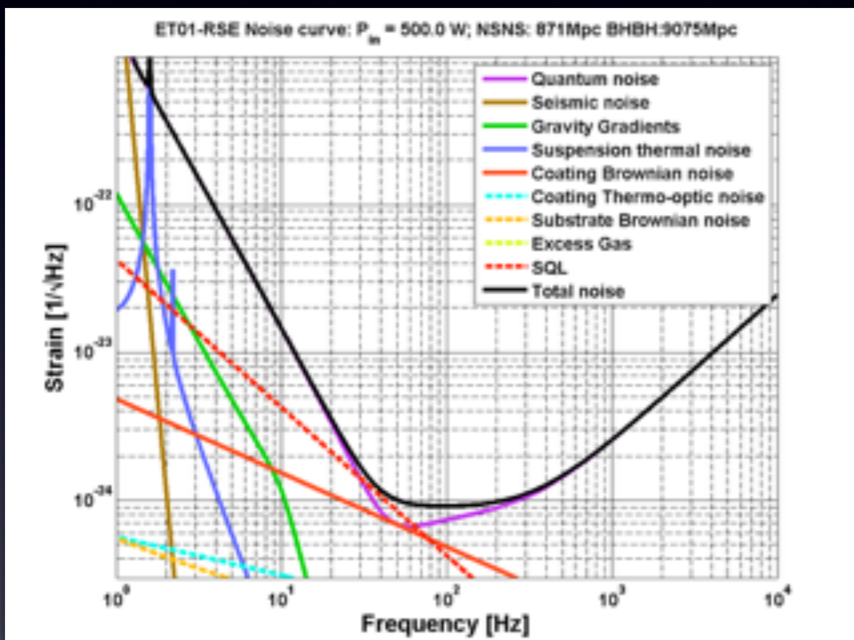


SAGNAC

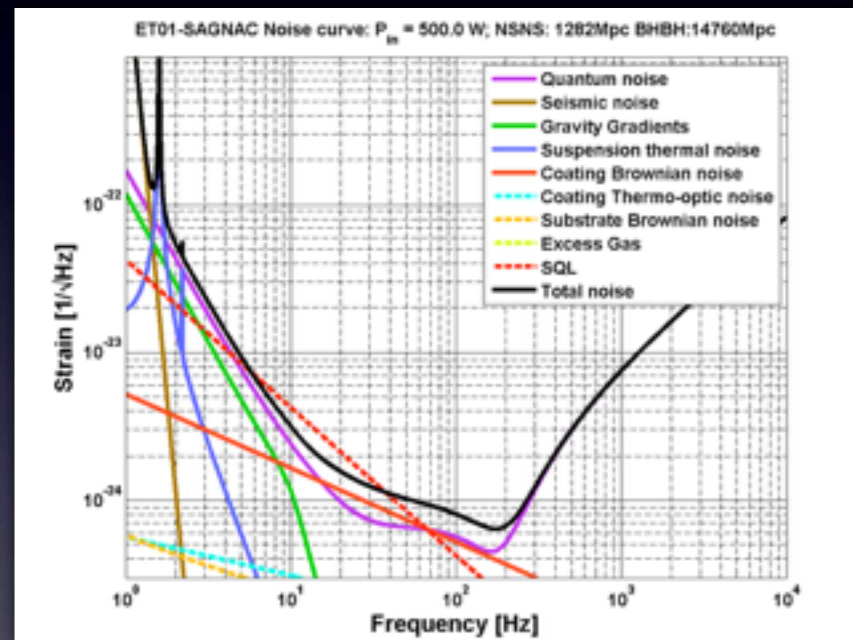


Sagnac vs. Michelson Example

RSE – tuned SR



SAGNAC-optimised



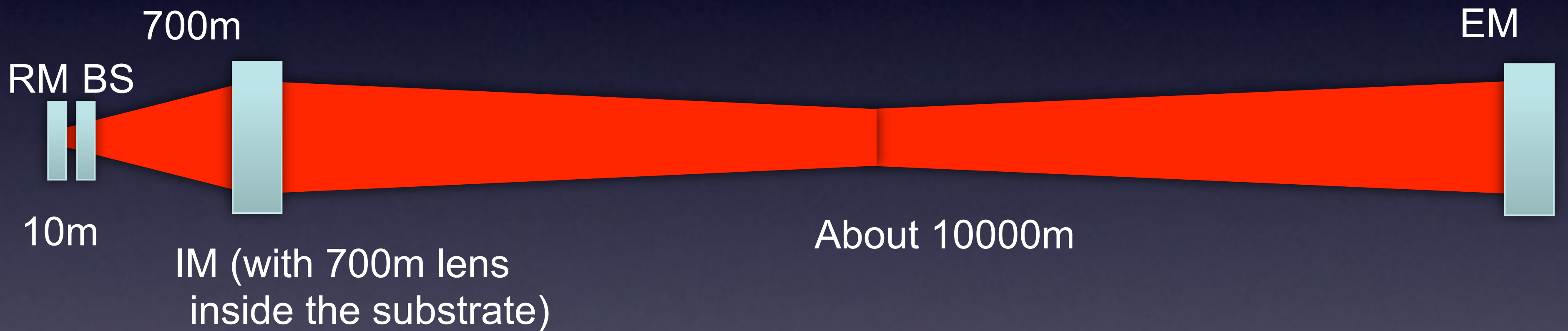
[S. Chelkowski, H. Müller-Ebhardt, S. Hild, 2009]

NSNS inspiral range for Sagnac topology 47% larger

Event rate increased by a factor of 3.2

Better Beam Sizes

- We want to have small beams in the central interferometer.
- This could be achieved by focusing the beam down between IM and BS



- In order to reduce problems from imperfect optics, the focusing should be rather gentle. For current design we assume 700m to focus from 8cm down to 1cm.

Minimal beam size