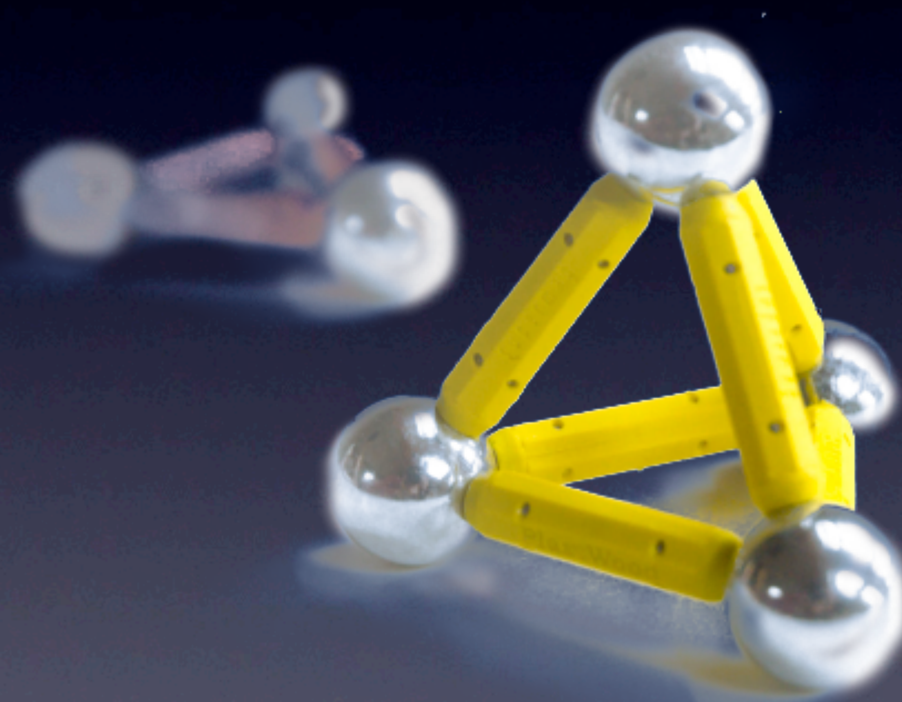
Einstein Telescope: The Interferometer Design



Andreas Freise
for the ET WP3 working group

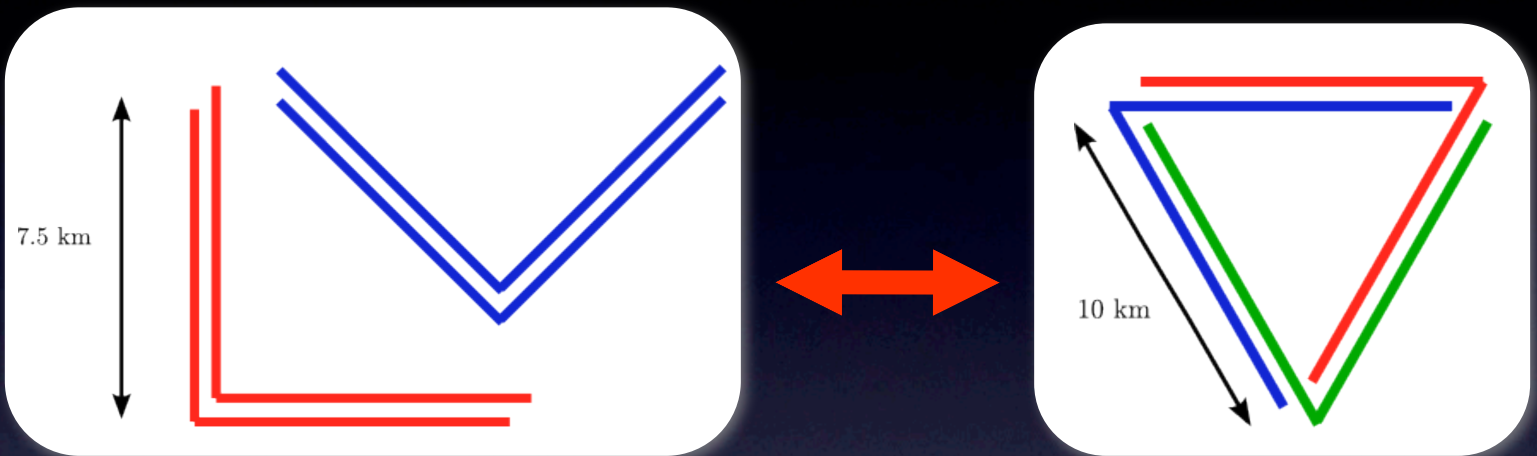
24.05.2011 GWADW Elba

Summary

- ET is a triangle of three detectors
- using two interferometers per detector
- Interferometers are Michelson plus recycling
- With squeezed light and Laguerre-Gauss modes

- Detailed optical layout

Multiple Interferometers



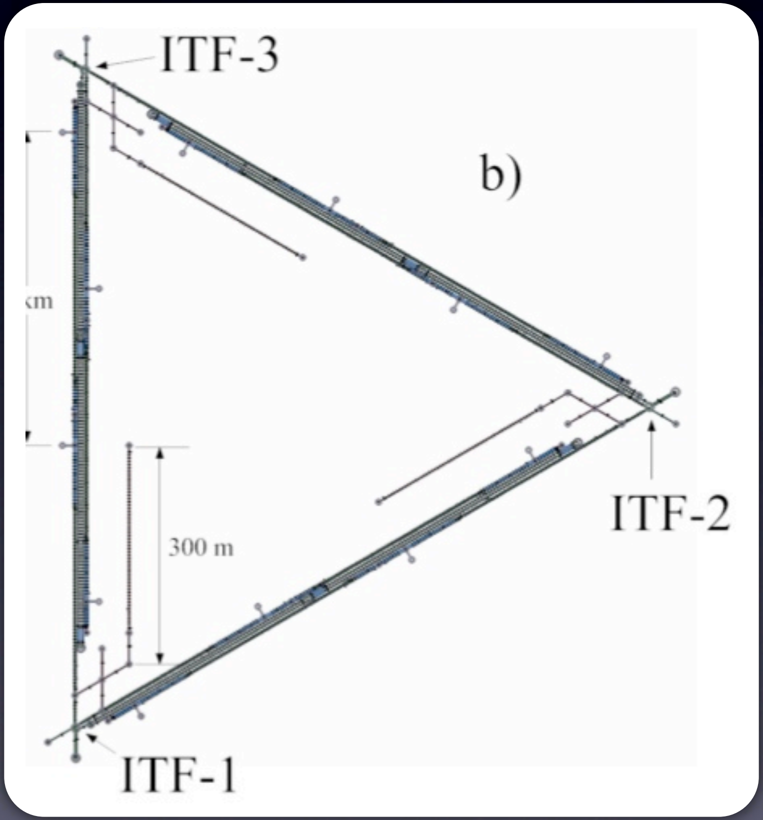
a. The L-shape provides the best form for a differential measurement of quadrupole waves

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

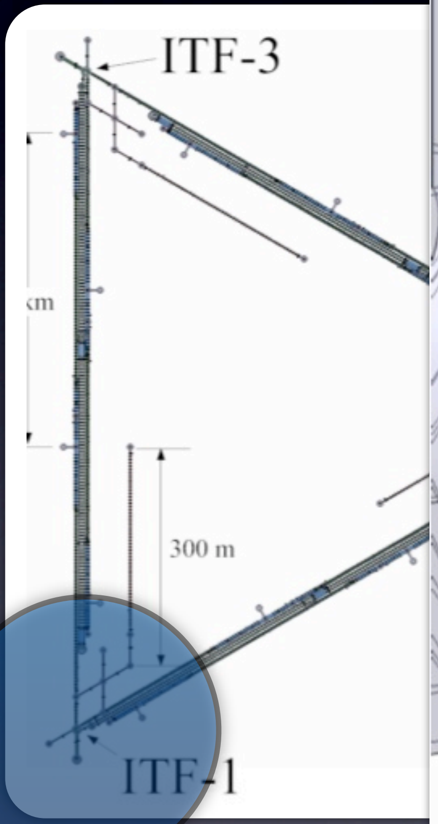
c. Two interferometers under 45 degrees can resolve both polarisations

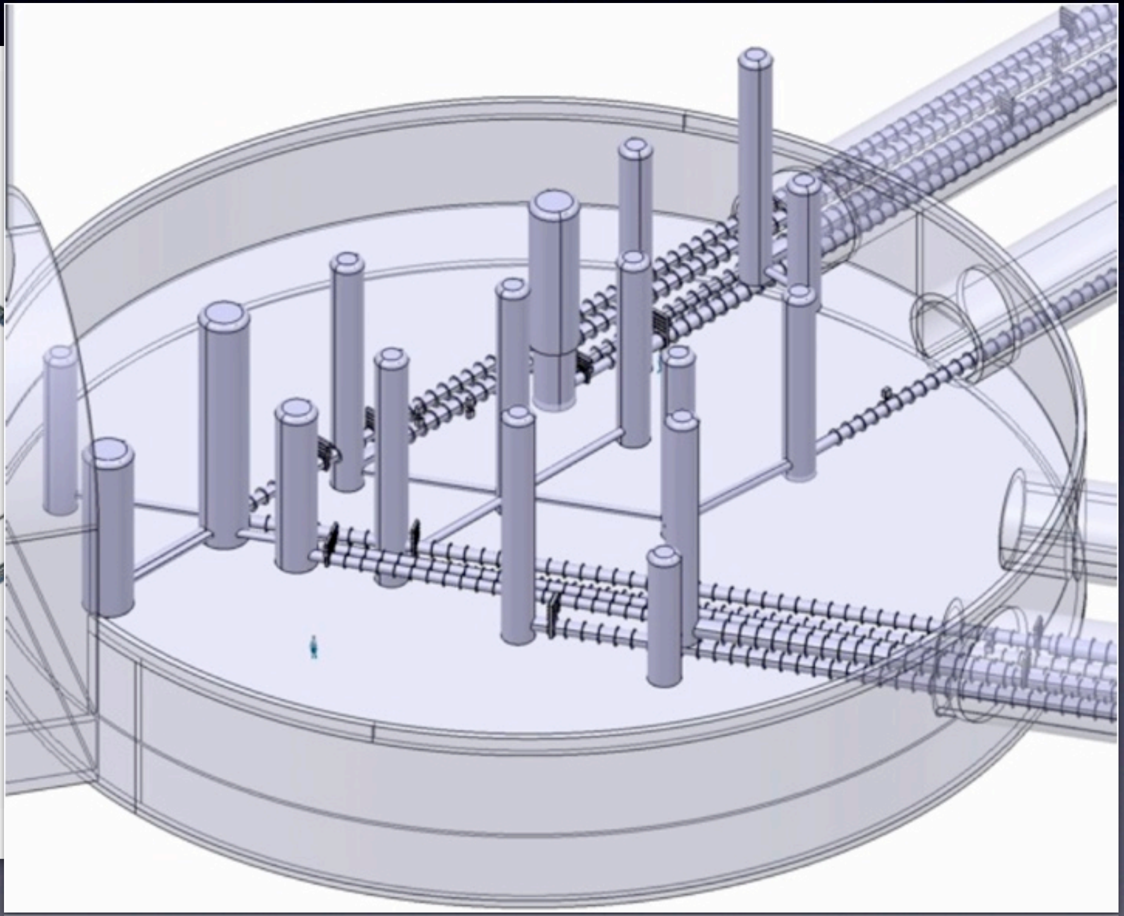
[A. Freise et. al.: Triple Michelson interferometer for a third-generation gravitational wave detector, Classical and Quantum Gravity, 2009, 26]

Triangle = less caverns



Triangle = less caverns





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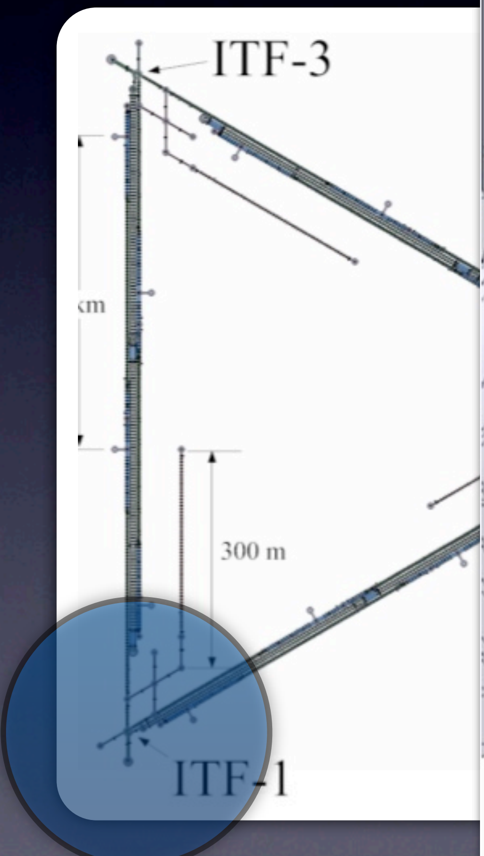
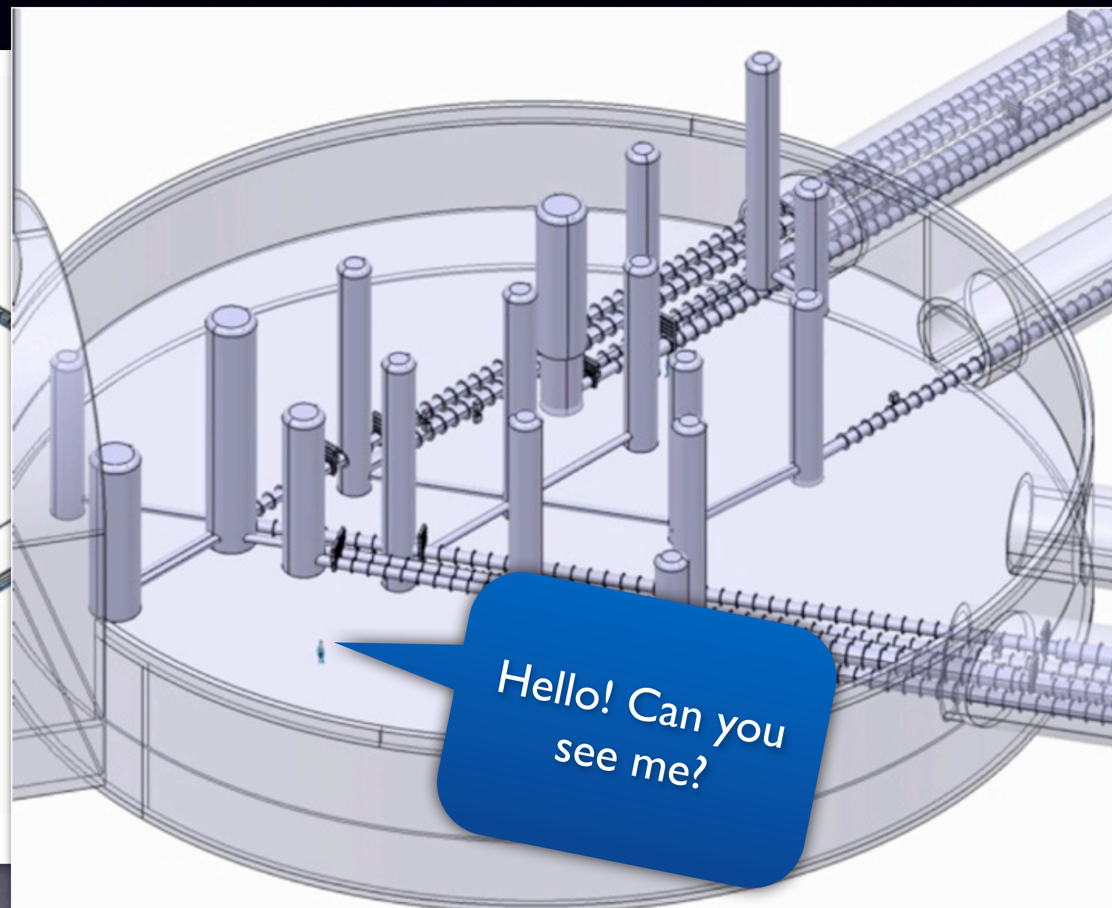
Triangle = less caverns



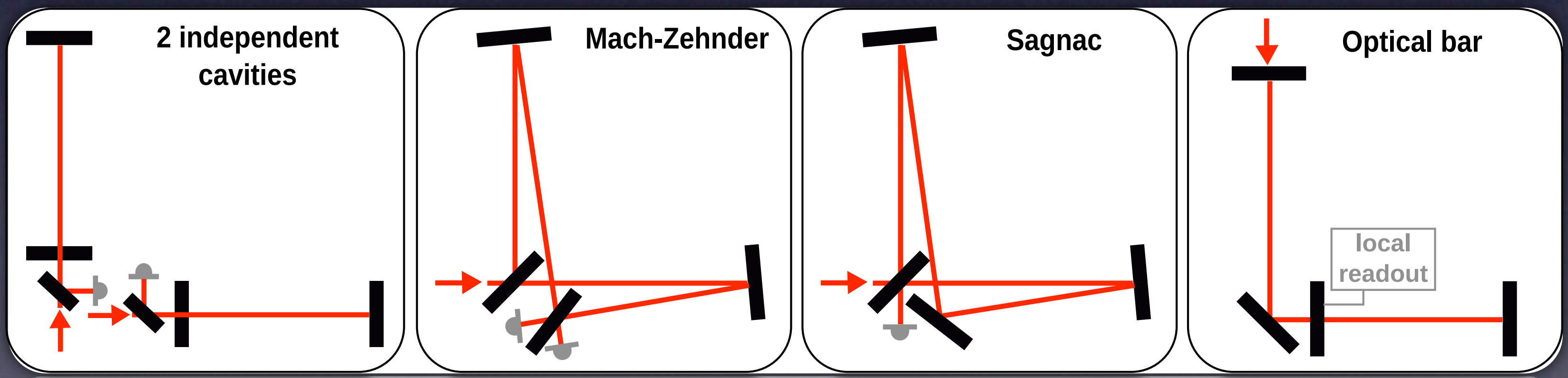


Interferometer Topology: Defined by Quantum Noise Reduction

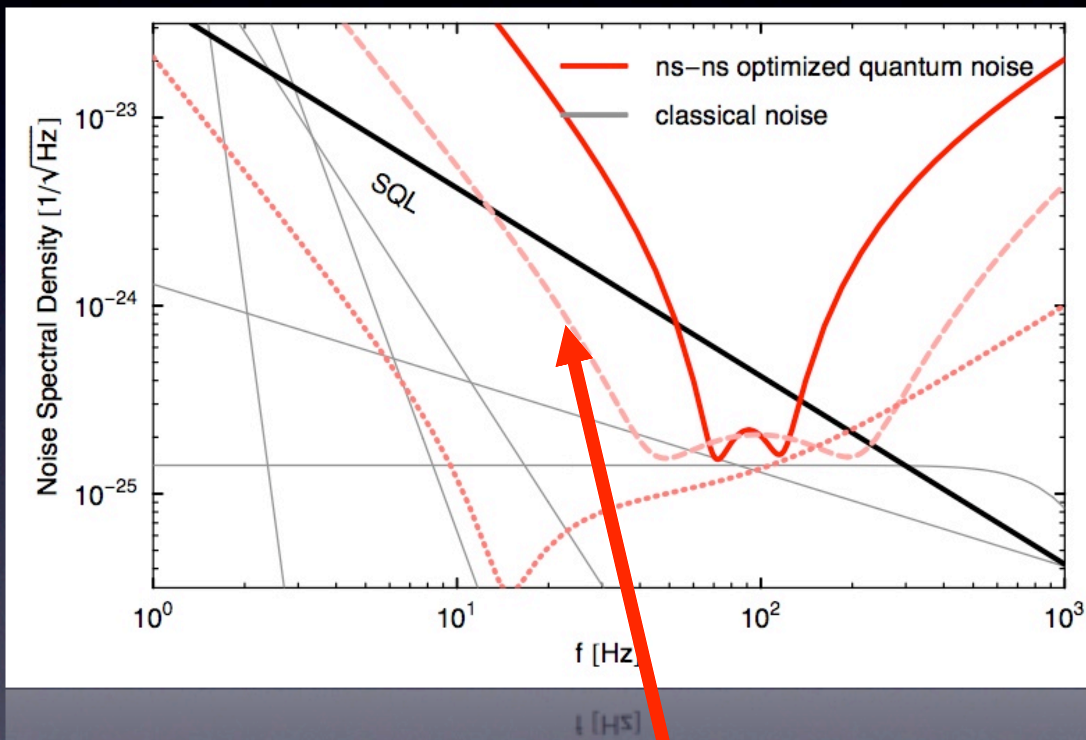
Several QNR topologies seem feasible:

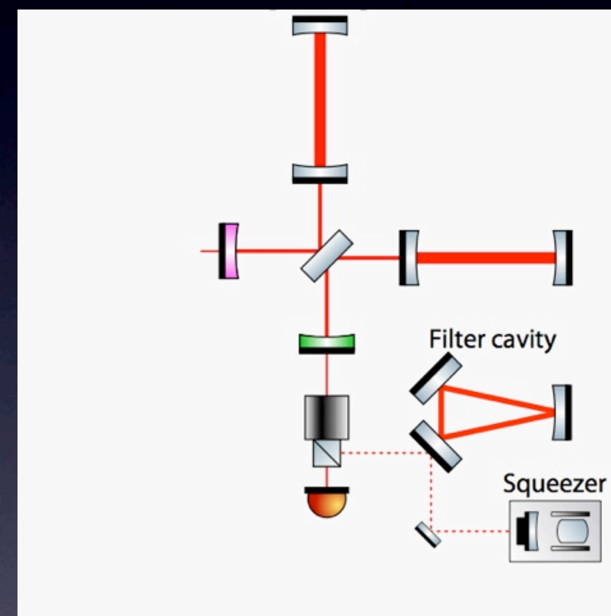
- Micheslon with SR, variational output, squeezing
- Sagnac or Mach Zehnder Interferometer with SR, …
- Optical bars, optical levers, double optical spring, …

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



Quantum Noise Reduction





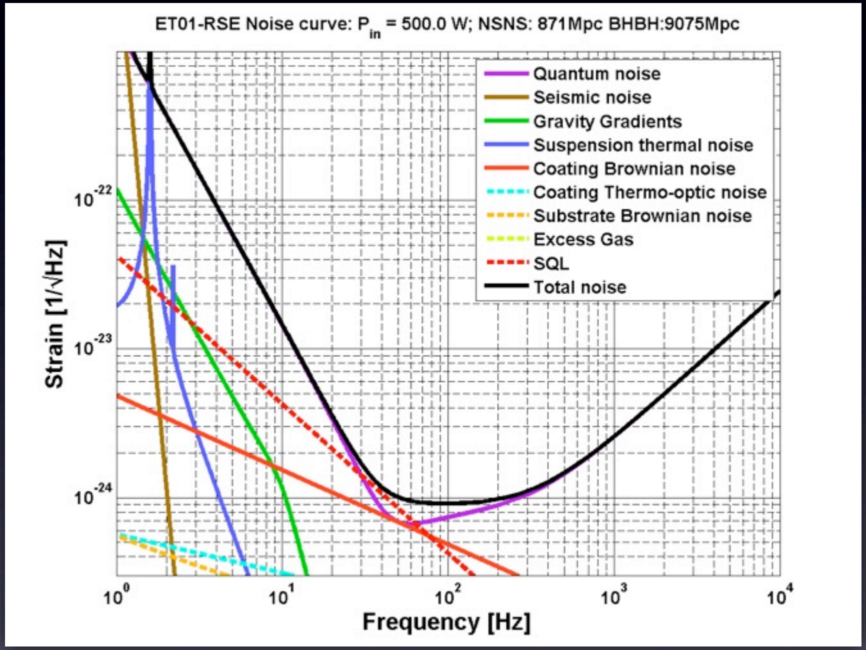
10dB frequency-dependent squeezing

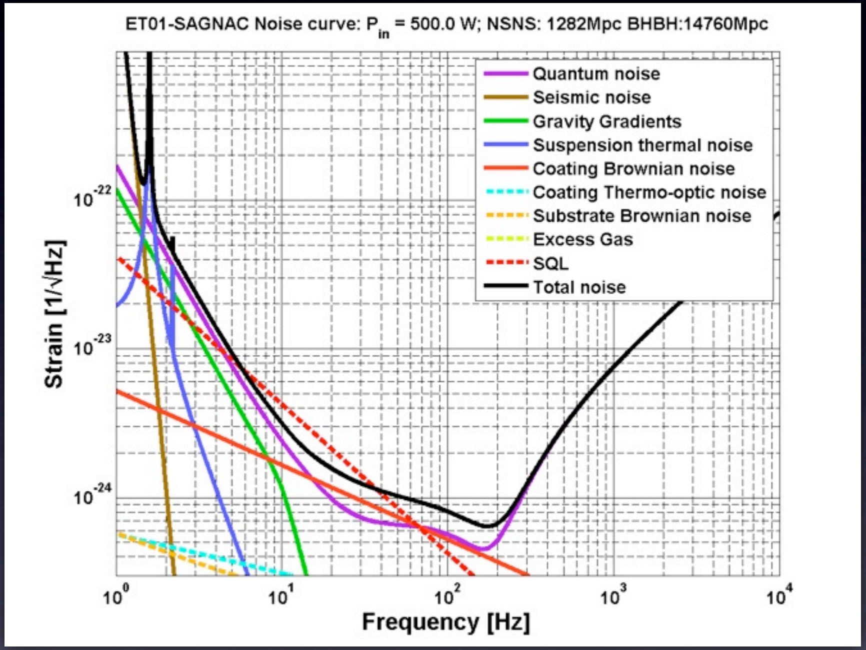
[H. Rehbein und H. Mueller-Ebhardt, ET note *ET-010-09* 2009]

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

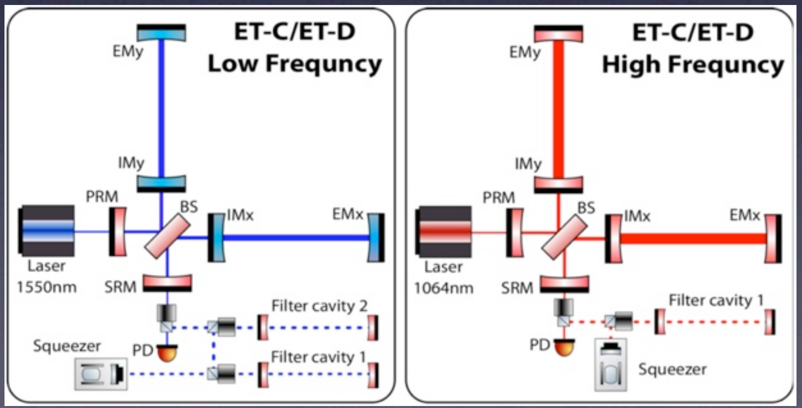
Topology summary

- Sagnac shows better quantum noise suppression
- However, it has one technical challenge: the ring-cavities in the arms requiring even larger mirrors
- 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
- Design can be changes easily to use a different QNR scheme later, if new research results recommend that

The Xylophone

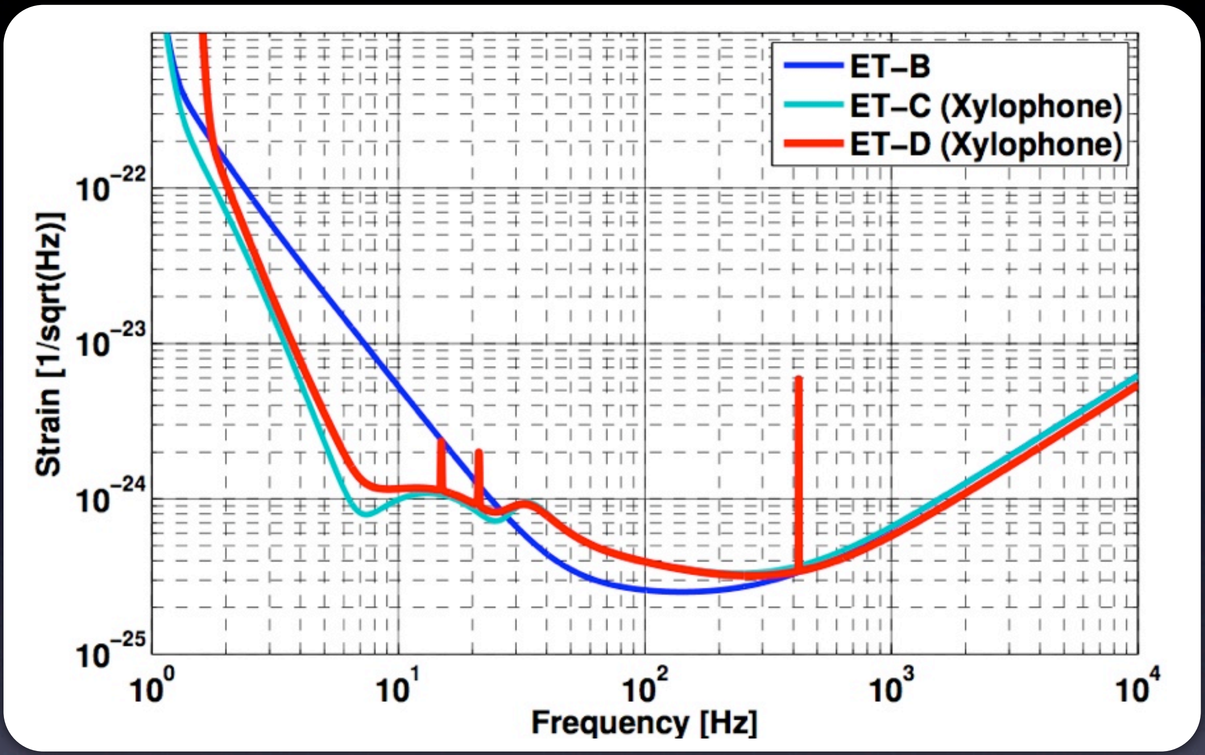
Each detector consists of two interferometer covering a part of the full frequency range.

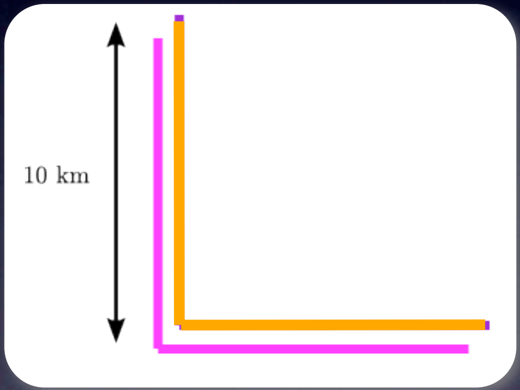
	range	power	lambda	T
LF	1.5 - 30 Hz	18 kW	1550 nm	arm: ~10 K, rest: 290 K
HF	30 - 10000 Hz	3 MW	1064 nm	290 K



EINSTEIN TELESCOPE
SEVENTH FRAMEWORK PROGRAMME

A leap foreward!



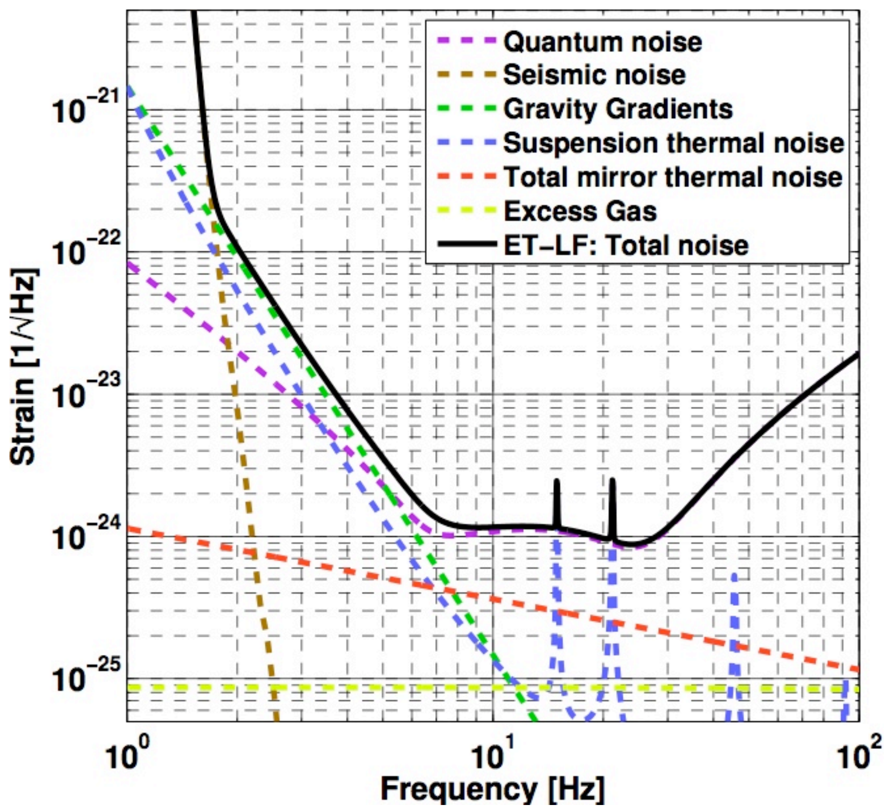


- Low power (no thermal effects), cooled, long suspensions
- High power, LG modes, room temperature, `normal' suspensions

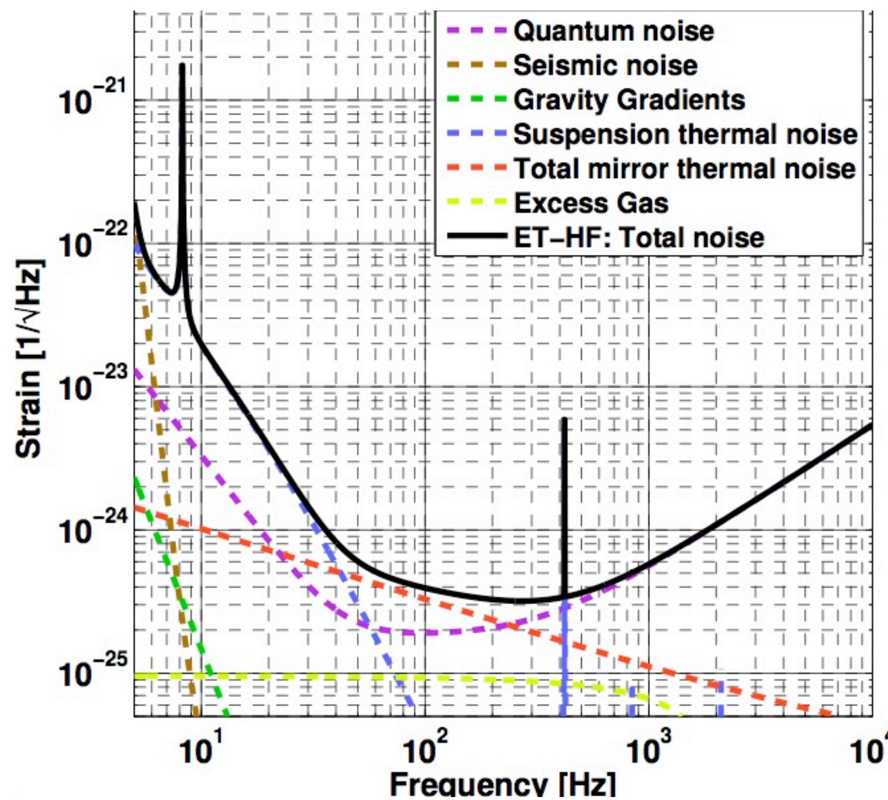
[S Hild et al: A xylophone configuration for a third-generation gravitational wave detector, Classical and Quantum Gravity, **2010**, 27]

Noise Budget

ET D LF



ET D HF



EINSTEIN TELESCOPE

SEVENTH FRAMEWORK PROGRAMME

Summary so far

- Broadband detector
- Three L-shaped detectors in a triangle
- Each detector consists of two interferometers

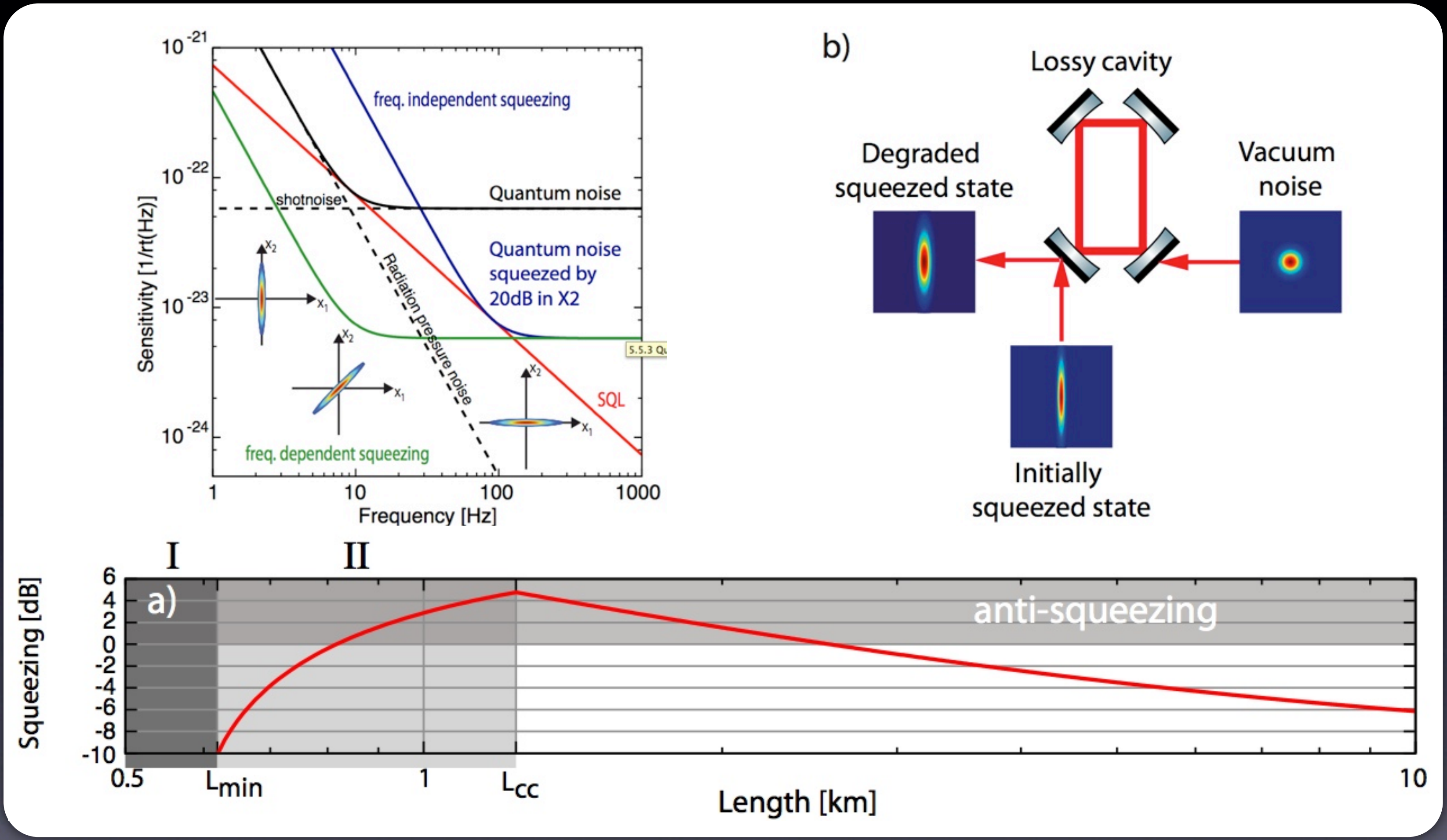
- Now for some details....

Squeezed Light

- ET requires 10dB effective squeezing
- HF: one 300 m long filter cavity
- LF: two 10 km long filter cavities

- Good experimental results in GEO 600!
- Ongoing R+D on filter cavities and 1550 nm squeezed light

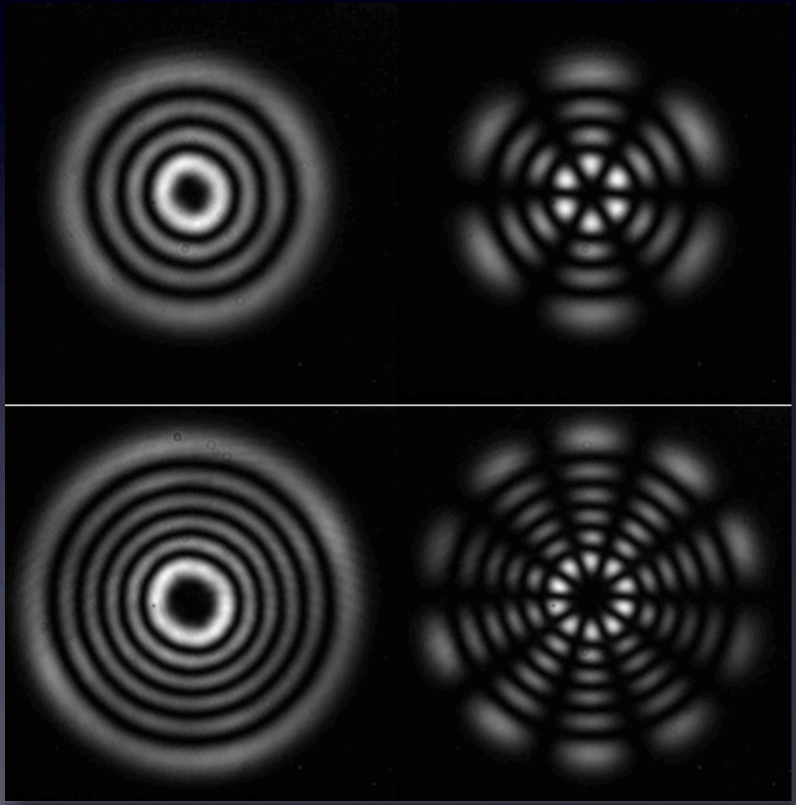
Filter cavities



[A Thuering, ET Design Study]

Reducing coating thermal noise: LG modes

Theoretical and experimental results: successfully locked a mode-cleaner to various higher-order LG modes. Ouput mode purity >99%. Simulations indicate problems due to mode degeneracy. Ongoing R+D.



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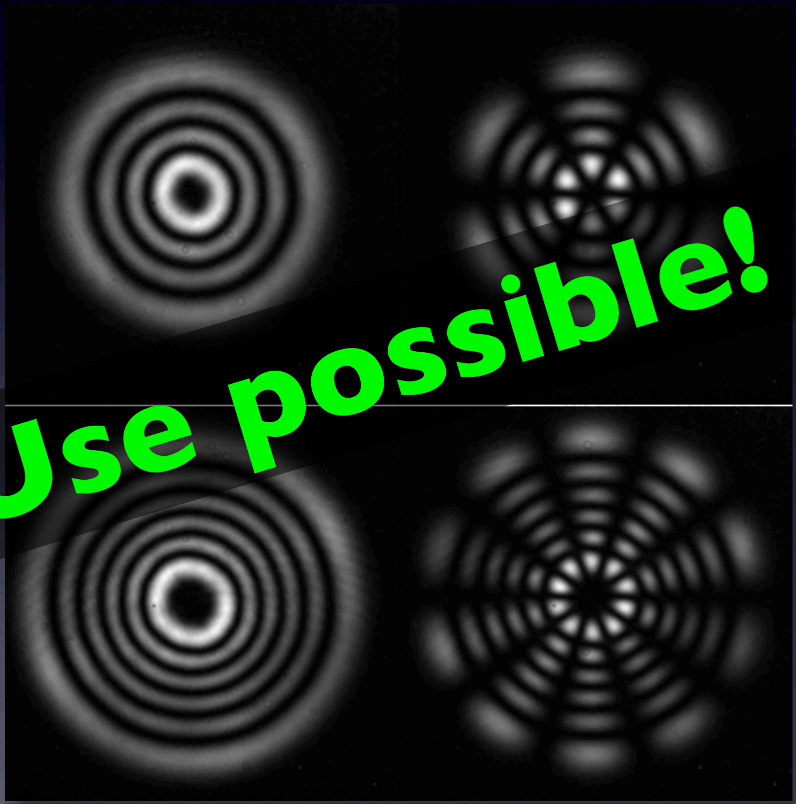
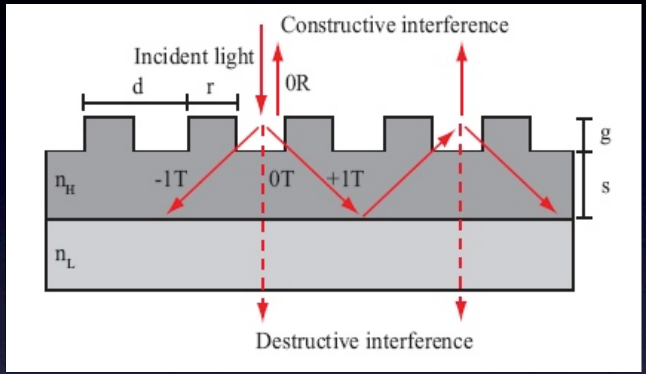
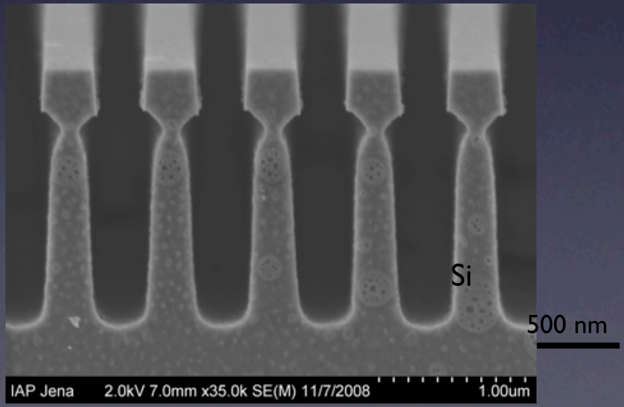


Waveguide Coatings

- Waveguides may provide another way to reduce coating Brownian noise.
- **Idea**: replacing the dielectric (lossy, thick) multi-layer stack by a (low loss, thin) mono-crystalline silicon nano-structure or a (thin) single layer diffractive coating.
- Experimental results from the Glasgow 10m prototype



Brückner et al., Optics Express 17 (2009) 163 – 169



Brückner et al., Optics Letters 33 (2008) 264 - 266

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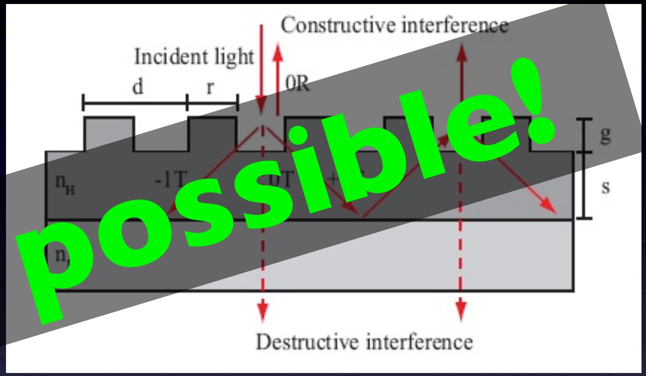
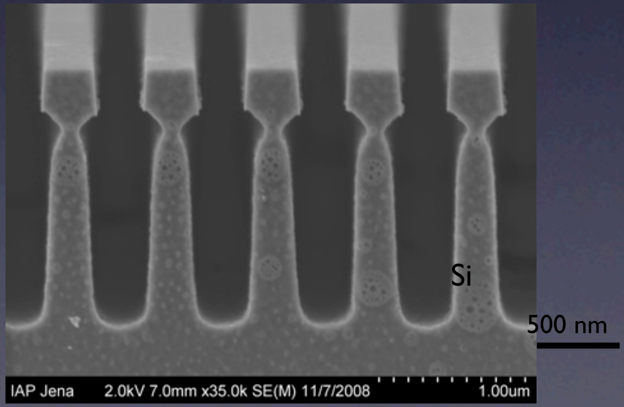
Use possible!



Brückner et al., Optics Express 17 (2009) 163 – 169



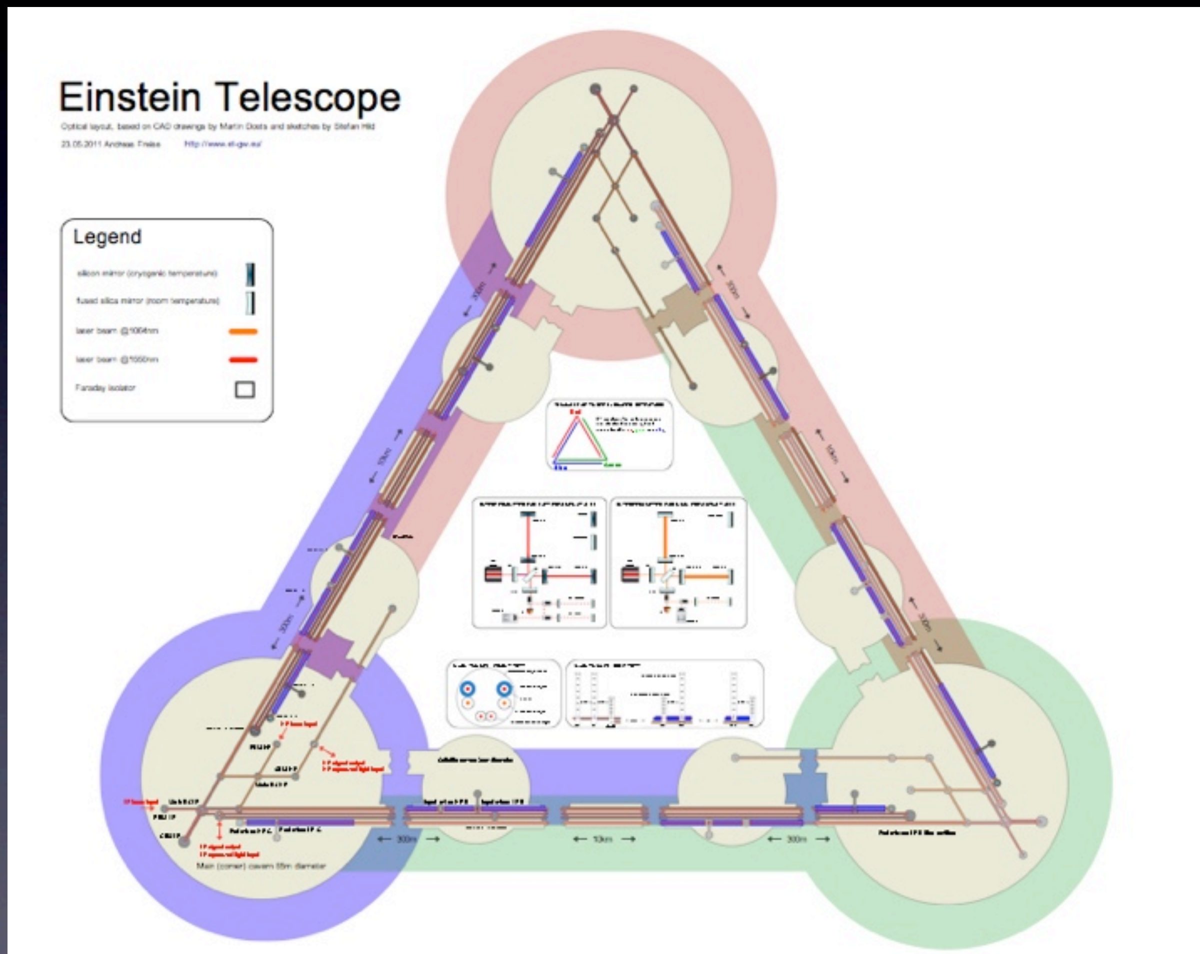
Brückner et al., Optics Letters 33 (2008) 264 - 266

`Standard Optical Technologies'

- For several technologies we found that we can now inherit and extend the work for Advanced detectors:
  - Injection system (mode cleaning)
  - Detection system (except for filter cavities)
  - Locking (Michelson with recylcing!)
  - Thermal compensation

Optical Layout

Interactive graphic at: http://www.et-gw.eu/



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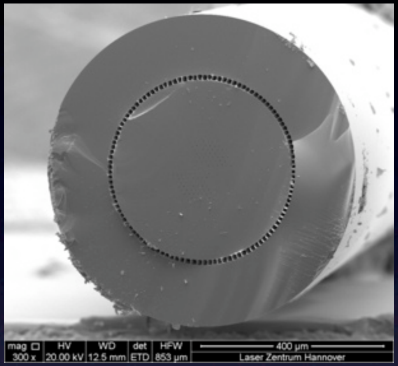
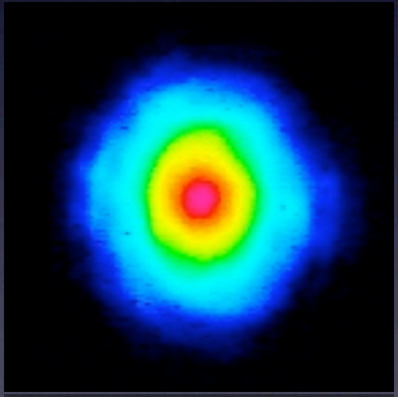
...end

Lasers

	LF	HF
lambda	1550	1064
beam shape	TEM00	LG33
power	6 W	1000 W





More R+D is required to reach these powers, but good experience with development for Advancend detectors

Mirrors

- All room temperature mirrors are fused silica
- Crygenic mirrors are silicon
- arm cavities:

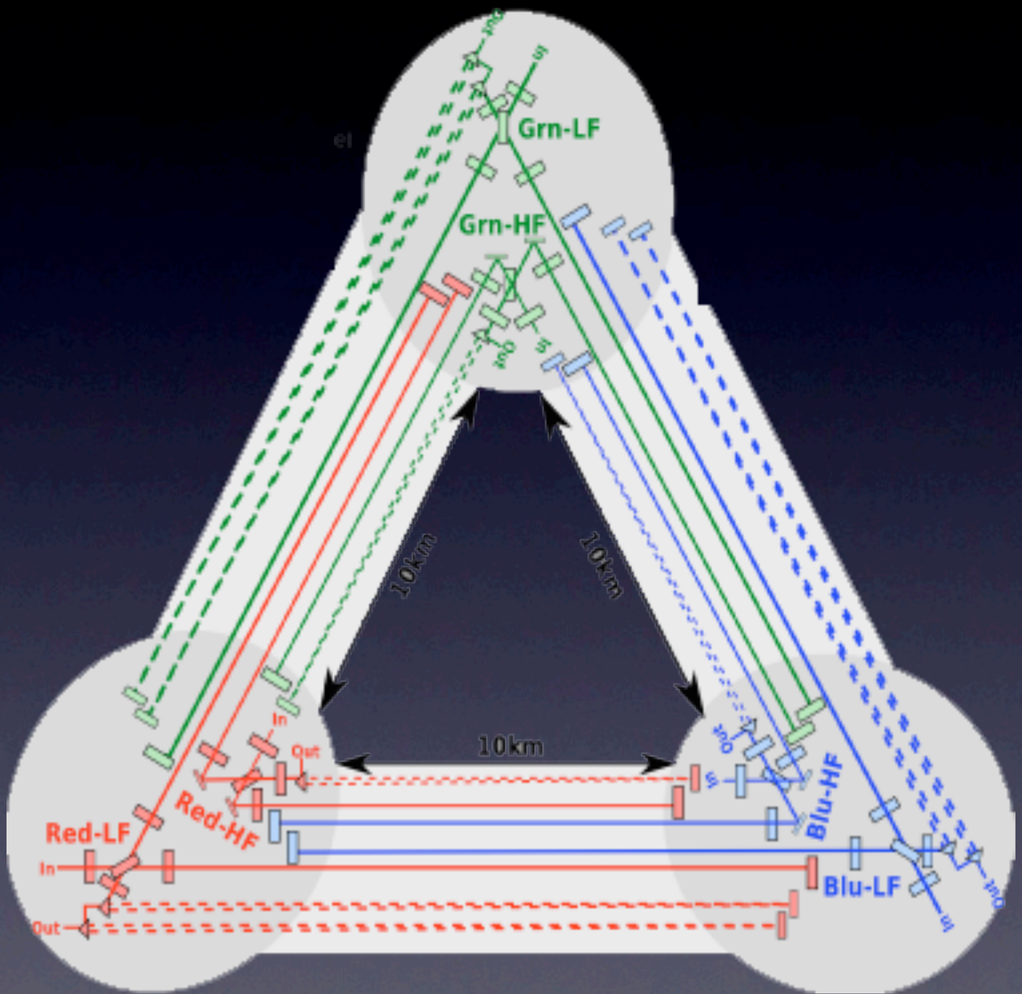
	LF	HF
mirror material	silicon	fused silica
mirror size	62 x 30 cm	45 x 50 cm
mirror mass	200 kg	211 kg
surface scatter loss	37.5 ppm	37.5 ppm
finesse	880	880
beam radius	9 cm	7.2 cm

Ongoing R+D on mirror surface quality, coating thermal noise, availability of silicon

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



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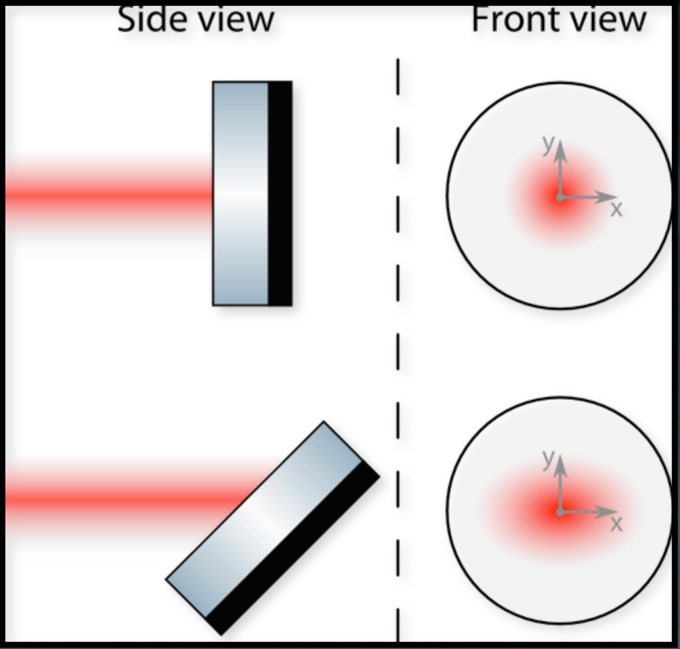
Mirror and Beamsplitter Size

Beam geometry on mirror surface depends on incidence angle:

$$I(x,y) = \frac{2}{\pi\, w_x\, w_y} \exp\left(\frac{-2x^2}{w_x^2}\right) \exp\left(\frac{-2y^2}{w_y^2}\right)$$
with $w_x > w_y$

The horizontal beam size is $w_x = w_y/\cos(\alpha)$. Thus also mirrors and especially beam splitters must be larger by the same factor.

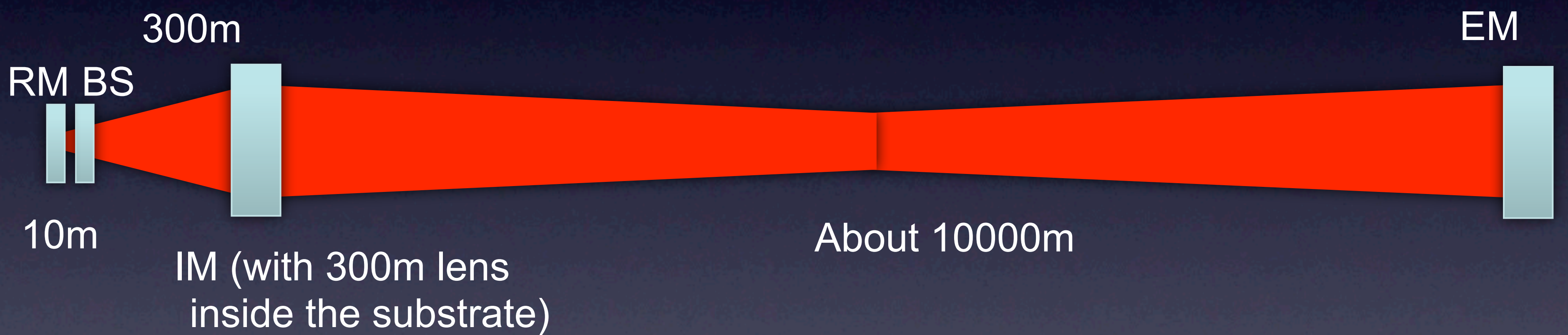


	BS diam. 45 deg	BS diam. 60 deg
LG33, 1064nm	80 cm	115 cm
LG00, 1550nm	60 cm	84 cm

→ These are considered to be too large.

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 300m to focus from 9cm down to <1cm.

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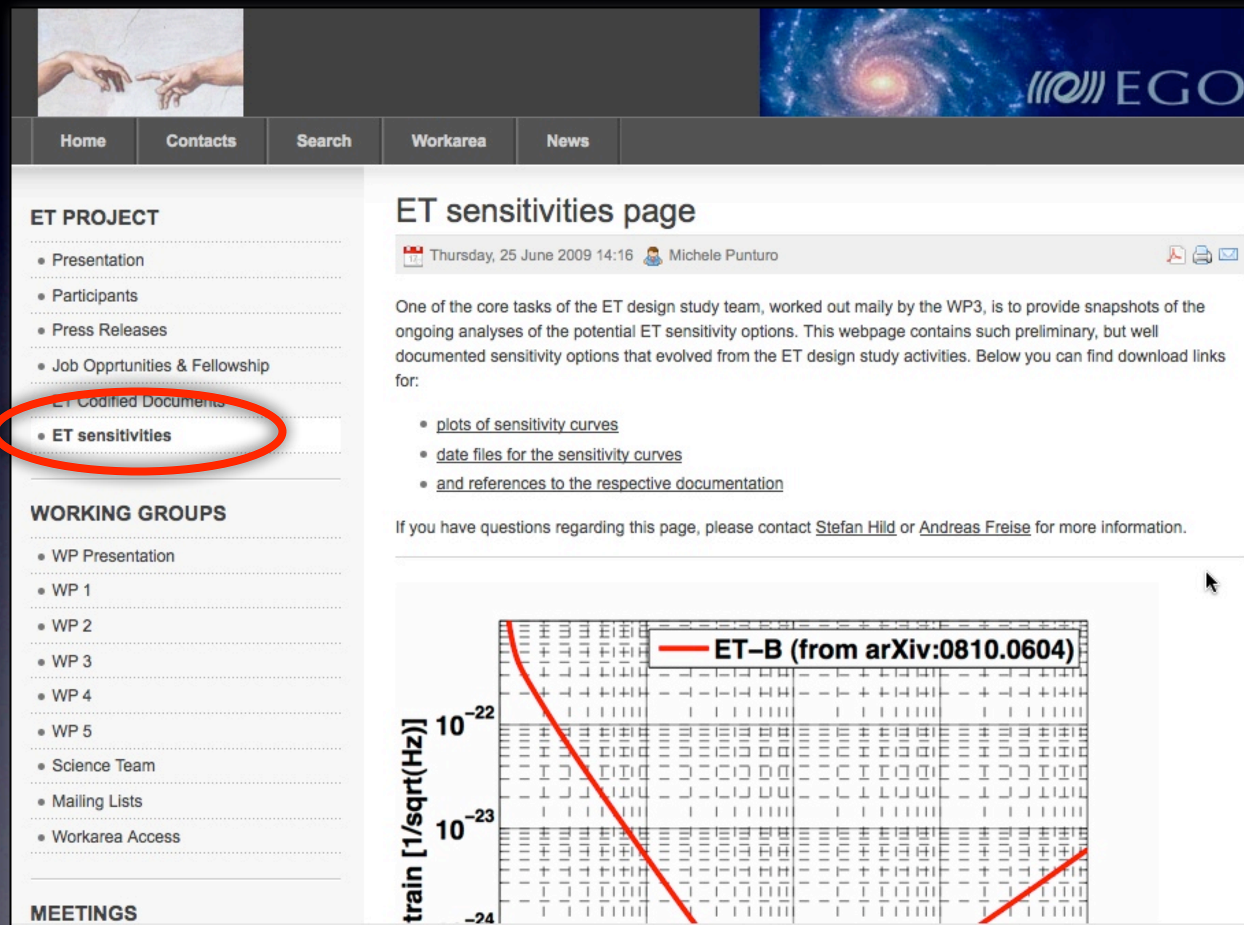
Sensitivity Studies

- One of the WG3 tasks is to provide official sensitivity curves
- Led by Stefan Hild but a transversal group effort: from sensitivity curve ET A, to ET B, ET C and now ET D.



`GW detector design is easy! I can do it!’

www.gwoptics.org