# News on the ET sensitivity curve

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# Overview

➢ These slides do not represent any coherent analysis and are only thought to provide an overview of various ongoing activities and ideas connected to the ET sensitivity.

➢ Topics of this talk:
- ➲ Overview of available sensitivity curves.
- ➲ Showing the weaknesses of the different curves.
- ➲ Requests for various input from WP4 to sensitivity curve discussions.
- ➲ Summary of what are the next steps towards a 'really' realistic sensitivity curve.

# The 'famous' ET sensitivity (ET-A)

➢ Blue line = 'famous' curve from an old FP6 proposal 2004.

➢ To avoid complicated names I call this sensitivity 'ET-A'.

➢ This curve is a good design target, however today we know that this curve is not necessarily realistic:

  ⮕ Curve entirely limited by quantum noise.

  ⮕ Gravity gradient noise not included.

  ⮕ Suspension thermal noise not included.

  ⮕ Not (well) documented.
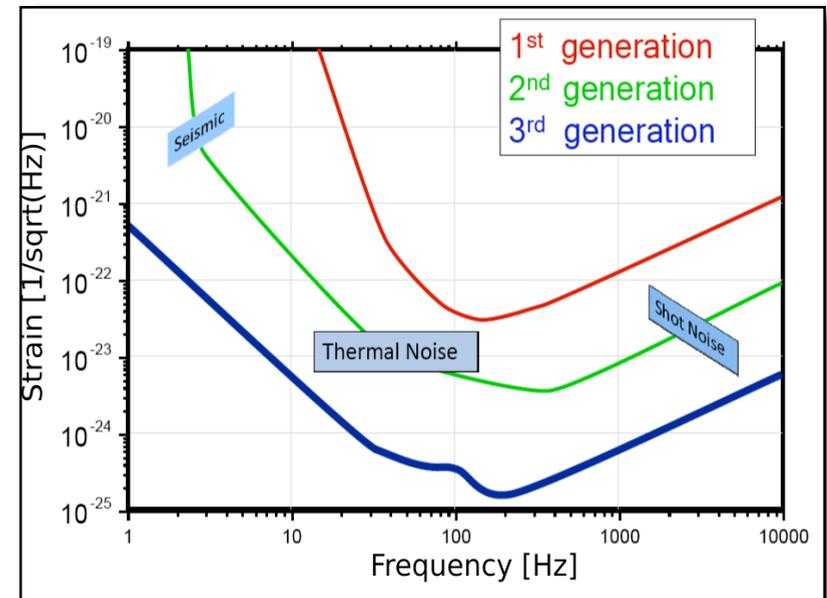
# ET sensitivity from arXiv:0810.0604 (ET-B)

➢ Aiming for a more realistic noise budget for ET.

➢ Used approach:
  ⮩ Only using conventional technologies (either available or up-scaled).
  ⮩ Starting from a 2nd generation instrument.
  ⮩ Configuration: Michelson + Arm cavities + power and signal recycling.
  ⮩ Arm length 10km.
  ⮩ Cover the full frequency band with a single instrument.

➢ Documentation and details can be found in S.Hild et al:
  arXiv:0810.0604 or at http://www.sr.bham.ac.uk/~hild/presentations/ET_brute_force.ppt

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EGO



ET dummy curve, file=ET_sthild_1.m — Start

ET dummy curve, file=ET_sthild_12.m — Result
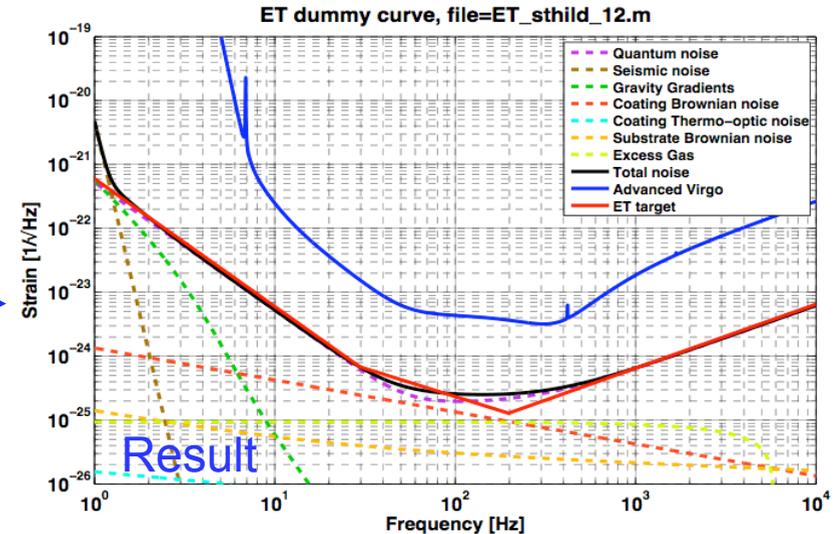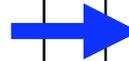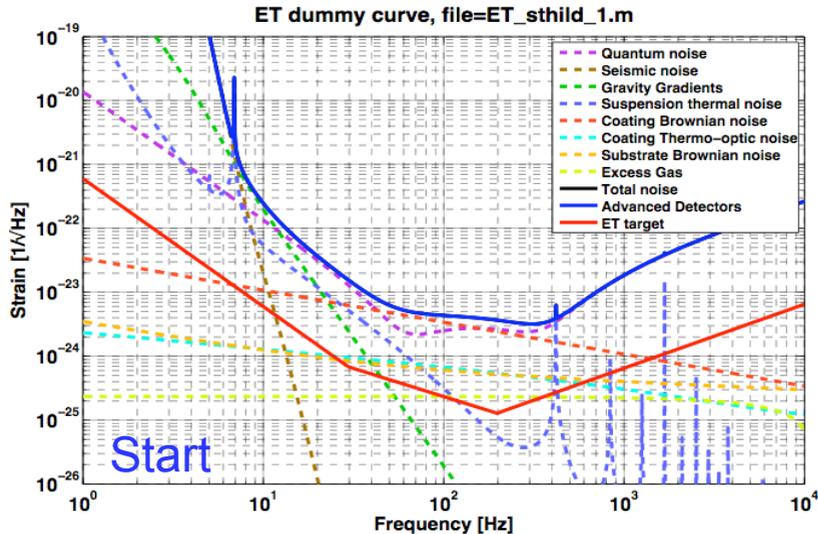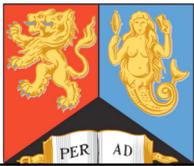
|  | advanced detector | potential ET design |
|---|---|---|
| Arm length | 3 km | 10 km |
| SR-phase | detuned (0.15) | tuned (0.0) |
| SR transmittance | 11 % | 10 % |
| Input power (after IMC) | 125 W | 500 W |
| Arm power | 0.75 MW | 3 MW |
| Quantum noise suppression | none | 10 dB |
| Beam radius | 6 cm | 12 cm |
| Temperature | 290 K | 20 K |
| Suspension | Superattenuator | 5 stages of each 10 m length |
| Seismic | $1 \cdot 10^{-7}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$ (Cascina) | $5 \cdot 10^{-9}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$ (Kamioka) |
| Gravity gradient reduction | none | factor 50 required (cave shaping) |
| Mirror masses | 42 kg | 120 kg |
| BNS range | 150 Mpc | 2650 Mpc |
| BBH range | 800 Mpc | 17700 Mpc |

# Availability of ET-B

➢ ET-B can be downloaded from the WG3 work area:

https://workarea.et-gw.eu/et/WG3-Topology

**Science Documents**

- An excerpt from the ET proposal: A general description of the ET design study as well as a summary description of the work covered by the WP3 group.
- Triple Michelson Interferometer for a Third-Generation Gravitational Wave Detector (arXiv): A review article on the idea of using Michelson interferometers in a triangular shape.
- Pushing towards the ET sensitivity using 'conventional' techniques: Analysis of how far the sensitivity of a 10km Michelson can be pushed by using only conventional technology (Also available at arXiv:0810.0604v1 [gr-qc]). This plot shows a comparison of the ET sensitivity from the initial proposal and this analysis. The data of the ET sensitivity from arxiv:0810.0604 can be found here: Matlab file containing two vectors for frequency and strain sensitivity (as amplitude spectral density).
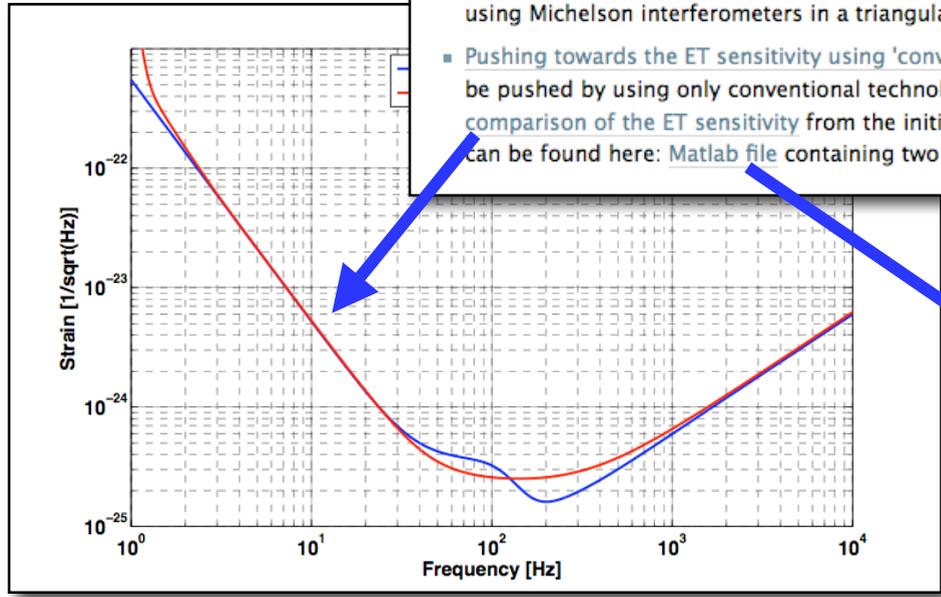


Matlab file (*.mat):

• frequency vector

• sensitivity vector (ASD)

# Major Weaknesses of ET-B

➢ Still no suspension thermal noise included.

➢ Gravity gradient noise for underground site so far only preliminary.

➢ Thermal noise of cryogenic temperatures need to be checked by experts.

➢ How can high optical power (several megawatts) go together with cryogenic mirrors (20K)?

*Nevertheless, there is plenty to learn from ET-B …*

# Some remarks to ET-B

➢ Gravity Gradient noise will be extremely challenging!

➢ Even with a quiet under-ground site we are still missing a factor 50 reduction to achieve target at 1Hz sensitivity.

   ➲ Clever Cave shaping?

   ➲ Measuring seismic and coupling to allow subtraction?
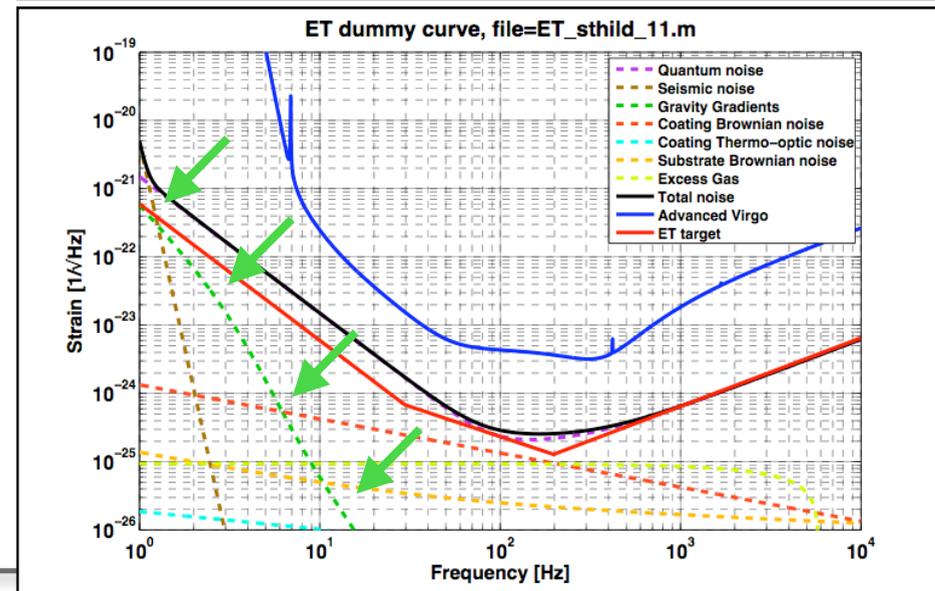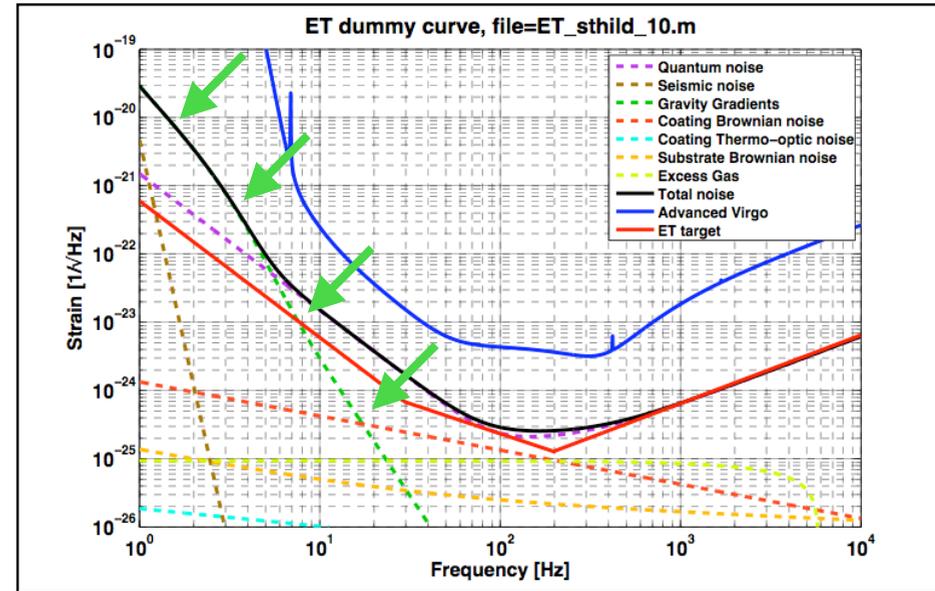
# Some remarks to ET-B

➢ However, if we would be able to deal with gravity gradient noise, then there might be a chance to get some 'easy and cheap' (heavier mirrors) increase of the sensitivity in the range between 3 and 30 Hz.
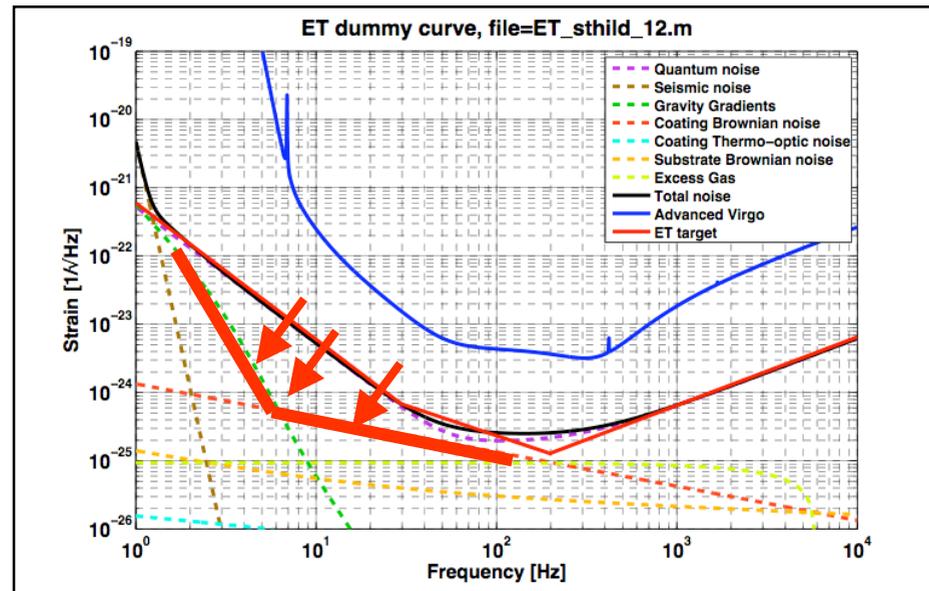
# WP4 input for sensitivity trade-offs ?

➢ I guess for WP1-WP3 it would be interesting to get input from WP4 for sensitivity trade-offs:

  ➲ To achieve ET-A around 1Hz will be experimentally very challenging/close to impossible.

  ➲ However, as shown on the previous slide we might be able to do much better than ET-A around 10 Hz.

➢ Can we trade-off a poor sensitivity below 3 Hz, by improved sensitivity around 10 Hz?

➢ How does the science we can do compare for the sensitivities displayed in **green** and **pink** ??



ET dummy curve, file=ET_sthild_12.m

Legend:
- Quantum noise
- Seismic noise
- Gravity Gradients
- Coating Brownian noise
- Coating Thermo–optic noise
- Substrate Brownian noise
- Excess Gas
- Total noise
- Advanced Virgo
- ET target
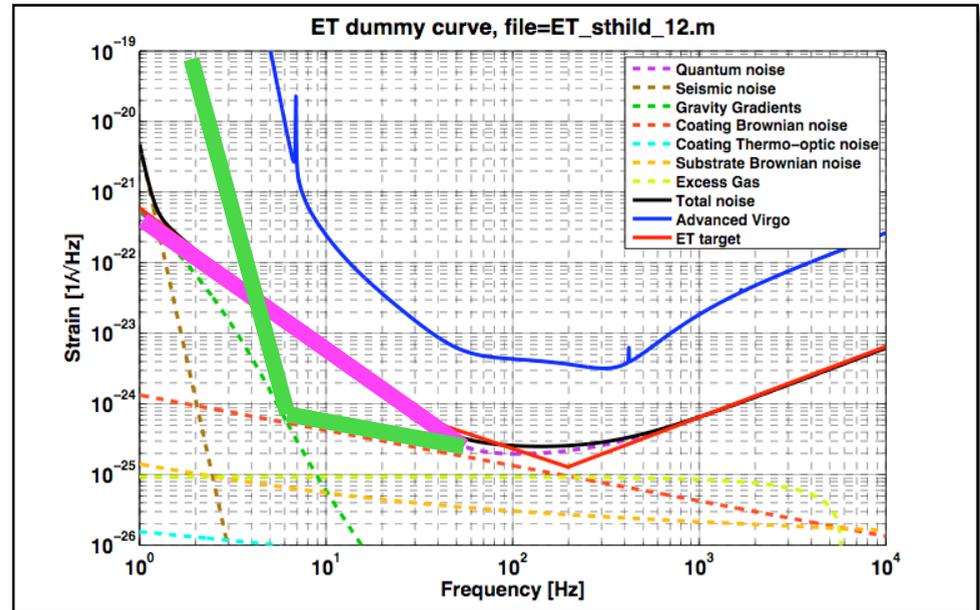
# Xylophone options

➢ For various reasons (for instance high power vs low temperature conflict) it might be beneficial to split the detection band into several detectors:

  ➲ Xylophone idea: Riccardo DeSalvo, Amaldi 2003.
  ➲ Each detector covers only a part of the targeted detection band.
  ➲ All detectors together will give the targeted sensitivity.

➢ Perhaps ET could be composed of at least 2, maybe 3 xylophone interferometers.

➢ Question for WP4: Are there any disadvantages connected to a xylophone ET compared to a single broad band detector?

# Xylophone Example: ET-B-Xylo



ET_sthild   Xylophone

Legend:
- **Advanced Virgo** (dashed blue)
- **ET target** (dashed red)
- **XYLO LF (18kW, SR phi=0.6, SR T=0.1) 50m suspension** (magenta)
- **XYLO HF (3MW, tuned, SR T=0.1) superattenuator** (purple)
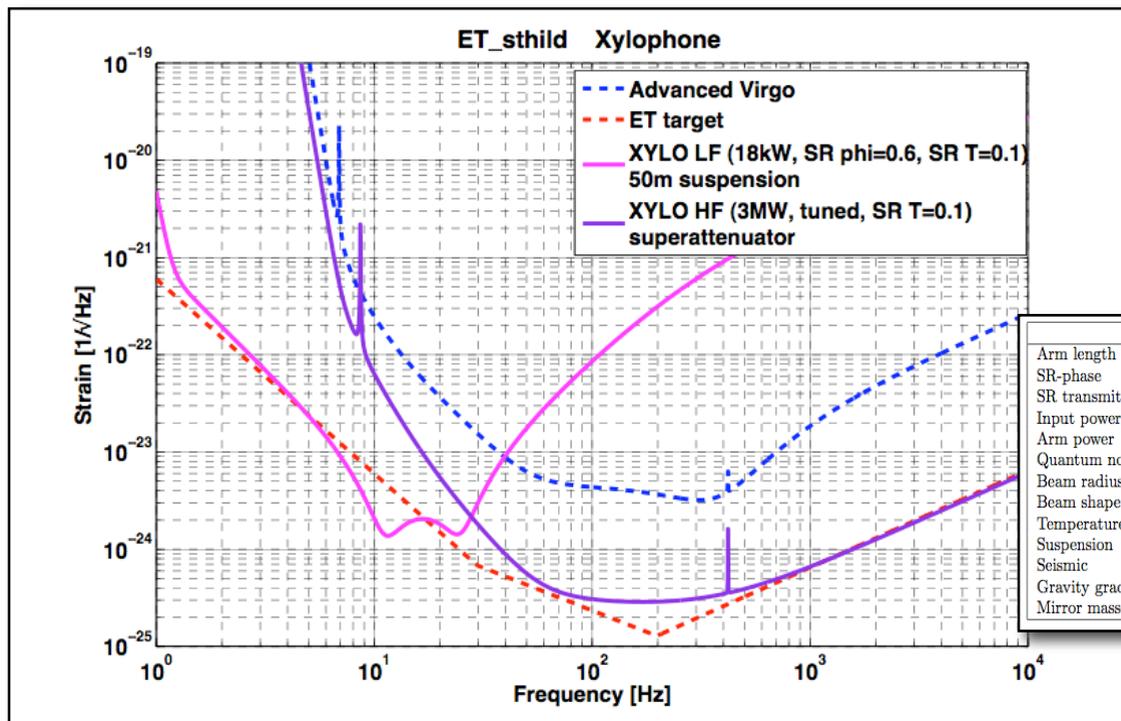
|  | ET high frequency | ET low frequency |
|---|---|---|
| Arm length | 10 km | 10 km |
| SR-phase | tuned (0.0) | detuned (0.6) |
| SR transmittance | 10 % | 10 % |
| Input power (after IMC) | 500 W | 3 W |
| Arm power | 3 MW | 18 kW |
| Quantum noise suppression | 10 dB | 10 dB |
| Beam radius | 12 cm | 12 cm |
| Beam shape | $LG_{33}$ | $TEM_{00}$ |
| Temperature | 290 K | currently 290 K, but need to gor cryogenic |
| Suspension | Superattenuator | 5 stages of each 10 m length |
| Seismic | $1 \cdot 10^{-7}\,m/f^2$ for $f > 1\,Hz$ (Cascina) | $5 \cdot 10^{-9}\,m/f^2$ for $f > 1\,Hz$ (Kamioka) |
| Gravity gradient reduction | none | factor 50 required (Subtraction technique?) |
| Mirror masses | 120 kg | 120 kg |

➢ HF detector: high power (3MW), room temperature, surface location, normal suspensions, LG33 mode, no gravity gradient noise subtraction…

➢ LF detector: low power (18kW), cryogenic, underground location, 50m suspensions, TEM00 mode, gravity gradient subtraction…

# Next steps I: Suspension Thermal noise

➢ We need to properly include suspension thermal noise into our models:

    ➲ Recent investigations for Advanced Virgo showed that there are always surprises…

➢ Are violin modes a problem from WP4 point of view?

    ➲ How much science do we loose when the sensitivity is spoiled with a 10Hz-comb of lines?

    ➲ What is the closest separation of violin modes that are tolerable? (50 Hz, 10 Hz, 2 Hz?)



**K. Somiya**
WP3 meeting, 01/2009
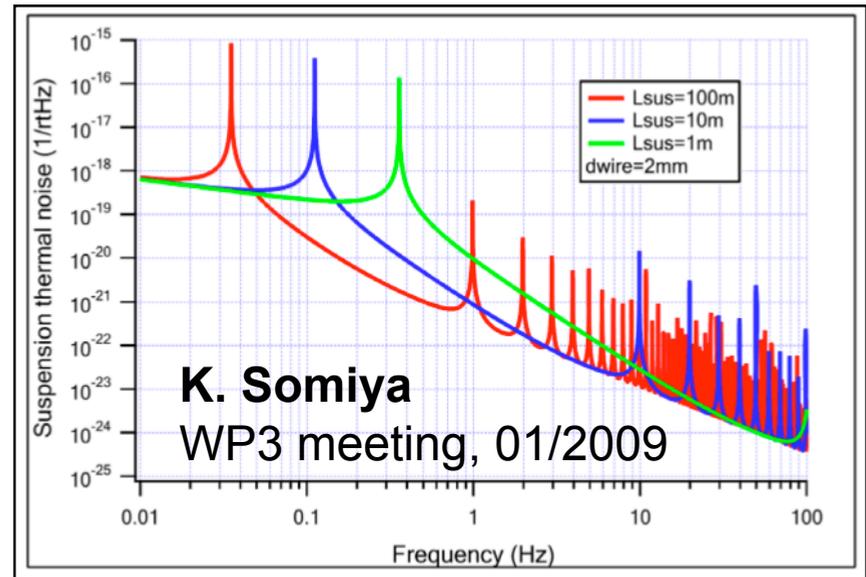
# Next steps II: Advanced Configurations

➢ We want to use the dual-recycled MI from ET-B as reference for analyzing more advanced configurations:

- ⊃ Dual Recycled Sagnac with arm cavities
- ⊃ Optical Levers



Dual Recycled MI

Mueller-Ebhardt
WP3 meeting, 01/2009

Dual Recycled Sagnac

Mueller-Ebhardt
WP3 meeting, 01/2009
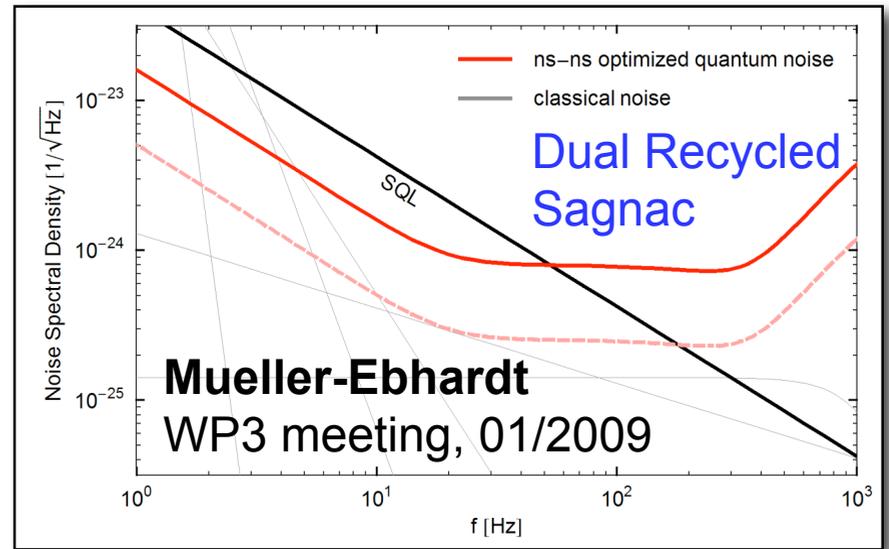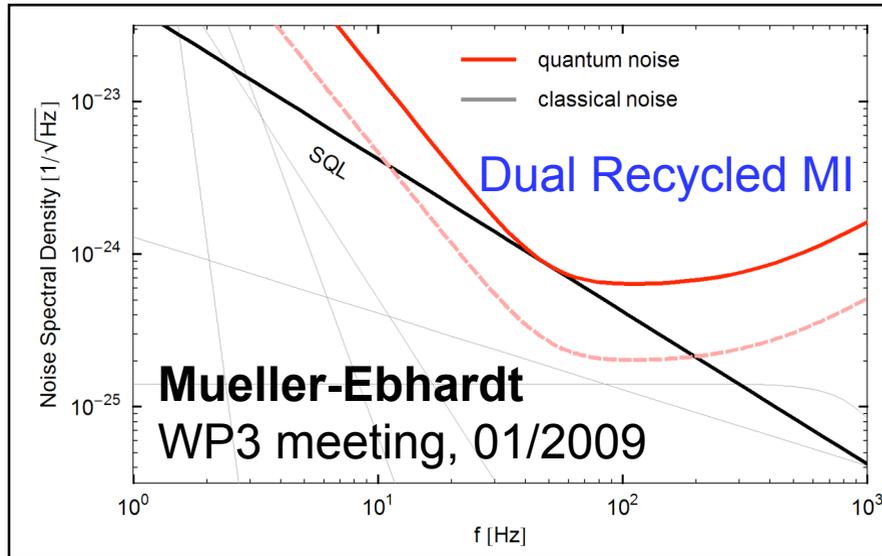
➢ Hannover has already computed and optimised the quantum noise of various configurations. However, still need to implement all other noise contributions for these new configurations.

# Summary

➢ ET-A is not (and has never been) an official ET target.

➢ ET-B gives roughly the same sensitivity as ET-A, but is more realistic and better documented.
- ➲ Data available on the web.

➢ **Input required from WP4:**
- ➲ Can we trade-off worse sensitivity below 3 Hz for better sensitivity around 10 Hz?
- ➲ Any problems if we go for xylophone configurations?
- ➲ How critical are line forests (violin modes from tall suspensions) for data analysis?

➢ ET-A and ET-B will NOT be the final ET-sensitivity! People are working on this topic and there will be more realistic sensitivity curves (ET-C, ET-D etc) coming over the next months. => Stay tuned!

➢ Please keep in mind: Providing a comprehensive and realistic sensitivity curve for ET is one of the main OUTCOMES of the design study.

# E N D