ET-ISB-Workshop, March 2021

Topic 3:

Facility Limits of the Einstein Telescope

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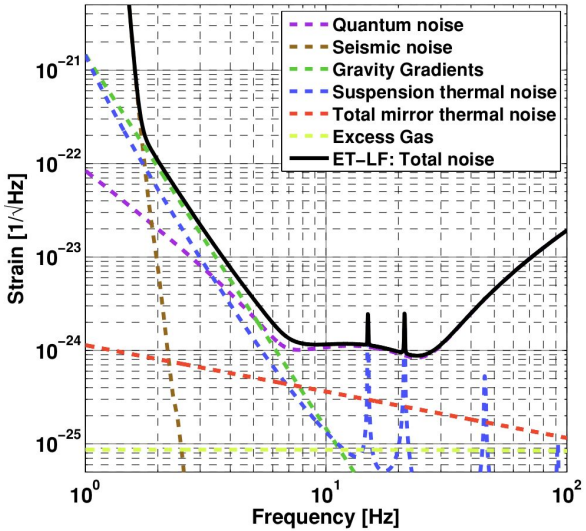
F. Ammann, M. Marsella, A. Utina ...

ET-0300A-21

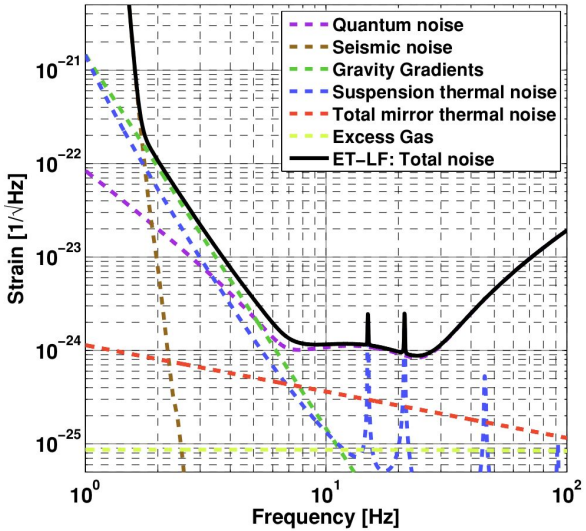
What do we mean by facility limits?

- A limit that cannot easily (or without considerable cost) be overcome once an observatory is build.



What do we mean by facility limits?

- A limit that cannot easily (or without considerable cost) be overcome once an observatory is build.
  - Example 1: Hard to extend the armlength by X km.
  - Example 2: You cannot further reduce your coating thermal noise by making your beamsize on mirrors larger than the aperture of your vacuum tube.
  - Example 3: It would be very difficult, if not impossible to cool the Virgo ITMs to 10K, because there is no space for heatshields.
  - Example 4: The vacuum level in your tubes sets a limit on residual gas noise, which is very hard to overcome.
- Note: Often people only refer to fundamental noise sources when discussing facility limits.



To what extend does the civil infrastructure set limits?

Some thoughts from Florian:

The **civil infrastructure and its interaction with the geology plays a role** (e.g. ventilation requirements, water ingress rate, pumps and size of sump, water flow in drainage system, dripping water, maybe consolidation related noise, etc.). Some of these sources can be eliminated by operational concepts (i.e. nobody is underground and thus ventilation is off), some need a better understanding, quantification and maybe a technical concept.

For the many years of operation, **noise sources may change over time** and conflicts of interest in surface and sub-surface utilization may arise. Many other stake holders exist (shallow and deep geothermal utilization, future wind mills, groundwater utilization, etc.). A In order to achieve a quasi static sensitivity over years, these infrastructure questions may become relevant.

Why is it important to determine the ET facility limits now?

- Anticipated operation according to ESFRI application 2035 to 2085!
- Detectors/Interferometers we design right now will just be the starting configuration.
- New generations of instrumentation should come in over the decades.

Why is it important to determine the ET facility limits now?

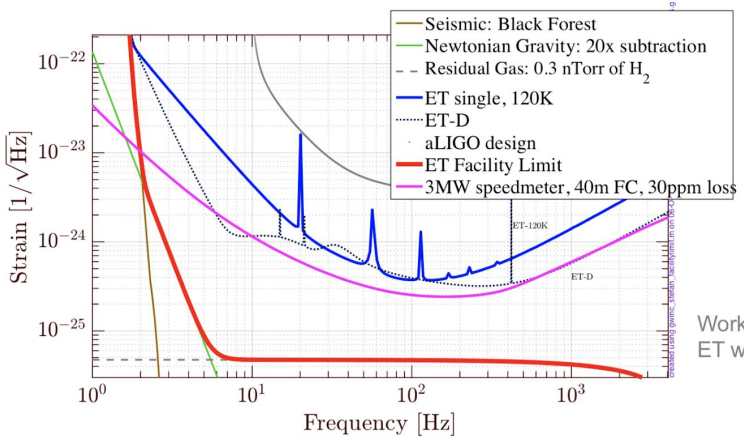
- Anticipated operation according to ESFRI application 2035 to 2085!
- Detectors/Interferometers we design right now will just be the starting configuration.
- New generations of instrumentation should come in over the decades.
- Knowing the ET facility limit allows us:
  - **to sell the story of upgrade strategy**
  - **to access what science could be achievable after upgrades**
  - **To evaluate on which noise sources we should work because they are above the facility limits.**

First rough estimate of ET facility limit from 2017 WS

Questions we need to answer as global community (IV)

How to “sell” the case for 3G GW observatories

- Sensitivity of first generation in new facility vs facility limits that will determine the sensitivity in ~2070?



Work carried out by all participants of ET workshop in Glasgow

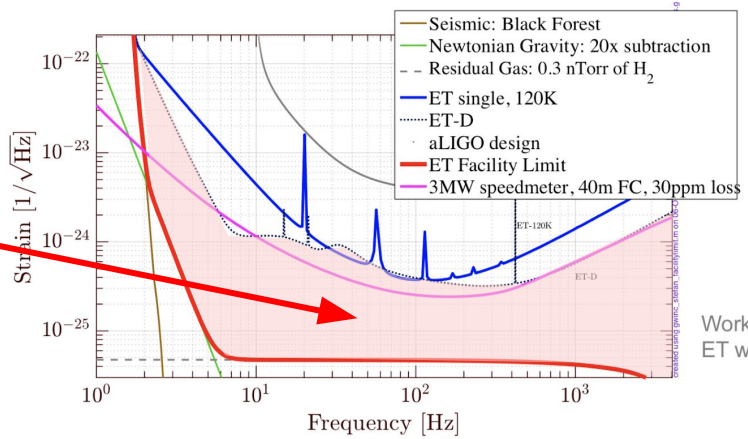
First rough estimate of ET facility limit from 2017 WS

Questions we need to answer as global community (IV)

How to "sell" the case for 3G GW observatories

- Sensitivity of first generation in new facility vs facility limits that will determine the sensitivity in ~2070?

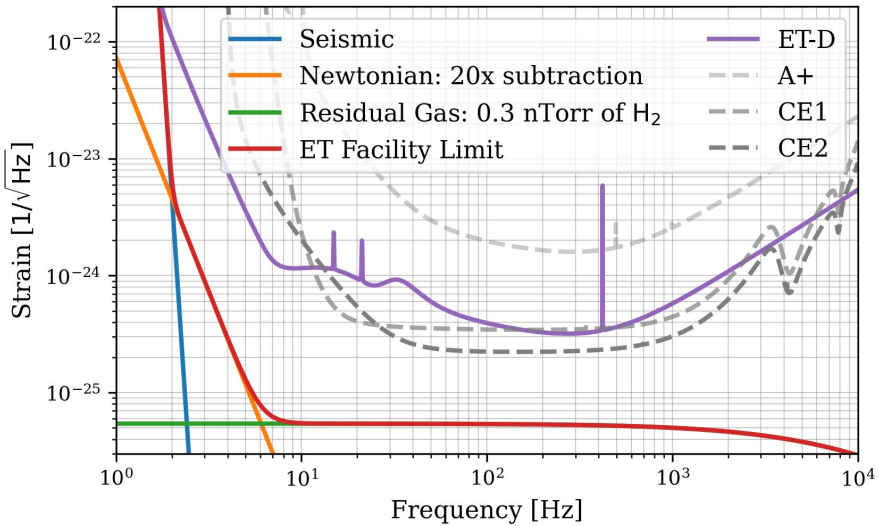
Space between ET-D and the ET facility limit can be explored in future upgrades



Work carried out by all participants of ET workshop in Glasgow

Fun Example of looking at the facility limit (Please do not take too serious!)

Plots created by WG III.1, i.e. Teng Zhang



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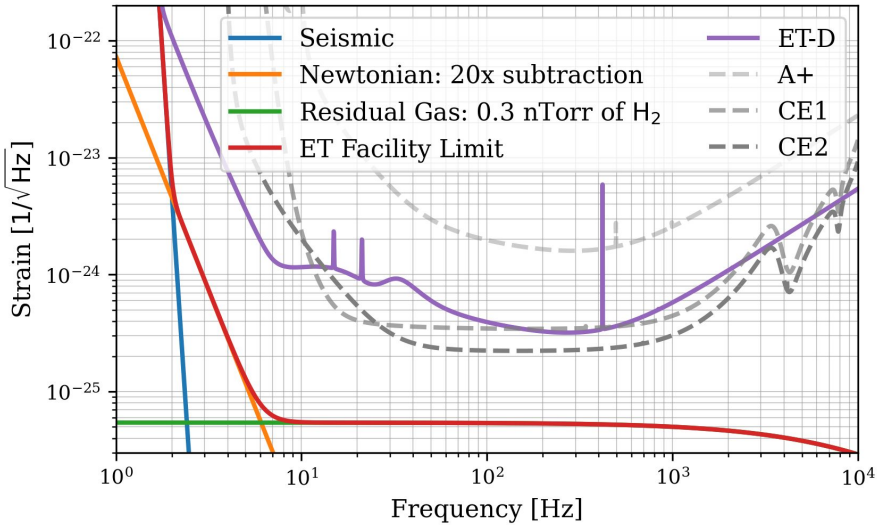
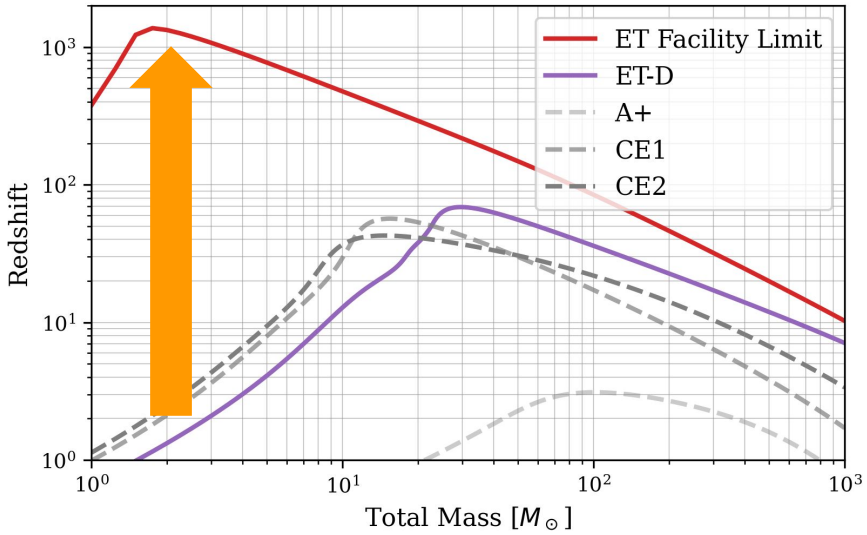
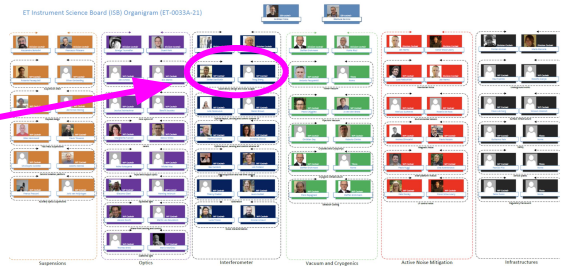




Could it be (would it be fascinating?) if ET in 2050+ or so would have a BNS horizon r>10 or even r>100 ? What scientific breakthroughs could be enabled?

Useful Resource provide by WG III.1: PyGWINC model

(= Observatory Design and noise budget)



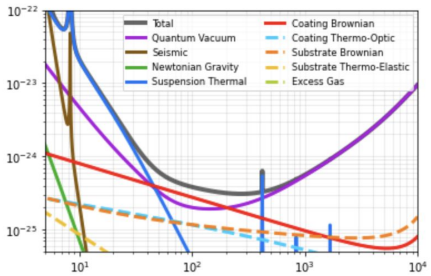
[5]:
```
import numpy as np
import matplotlib.pyplot as plt
import gwinc
import squeezingFC
from gwinc.ifo.noises import ifo_power
from gwinc.ifo.noises import arm_cavity
```

[6]:
```
freqHF = np.logspace(0,4,3000)
budgetHF = gwinc.load_budget('ETHF',freq=freqHF)

# Example of adjustable parameters
#budgetHF.ifo.Infrastructure.Length=10000
#budgetHF.ifo.Optics.Curvature.ITM.Curvature=5070
#budgetHF.ifo.Optics.Curvature.ETM.Curvature=5070
#budgetHF.ifo.Materials.Substrate.Temp=290
#budgetHF.ifo.Squeezer.AmplitudedB=0

budgetHF.ifo.Squeezer.FilterCavity=squeezingFC.computeFCParams(budgetHF.ifo)
tracesHF = budgetHF.run()
fig = gwinc.plot_budget(tracesHF)
plt.xlim(5,10000)
plt.ylim([5*10**(-26), 1*10**(-22)])
```

[6]:
```
(5e-26, 1e-22)
```



- Available on https://gitlab.et-gw.eu/ https://gitlab.et-gw.eu/et/isb/interferometer/wpiii.1-observatory-design-and-noise-budget..git
- Contains noise budgets for ET-LF and ET-HF
- Requires PyGWINC and Inspiral-Range packages to run
- Can be run as Jupyter notebook
  - `Run.ipynb` for noise budget plots
  - `Run_horizon.ipynb` for Redshift-Mass plot
  - `Param_change_example.ipynb` for example of how to modify parameters and compare noise budgets

What would like to do over the next 2-3 days?

Subgroup 1:

1. Identify which noise sources set the facility limit for ET.
2. Agree on a model/parameters describing the limit for each of the relevant noises
3. Compile and document an updated ET facility limit strain curve.

Subgroup 2:

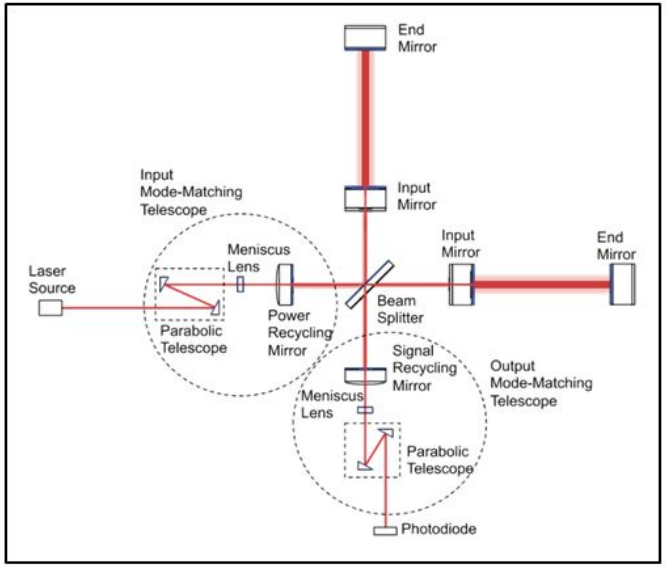
Answer the question: “Using the current ET infrastructure design (cavern locations/dimensions; arrangement of vacuum tubes), which concepts and technologies do we exclude upfront?”

For example: current setup foresees telescopes in MICH, i.e. between BS and ITMs and does not easily allow for pushing these telescopes in front of BS.

Illustrating Example: Telescopes

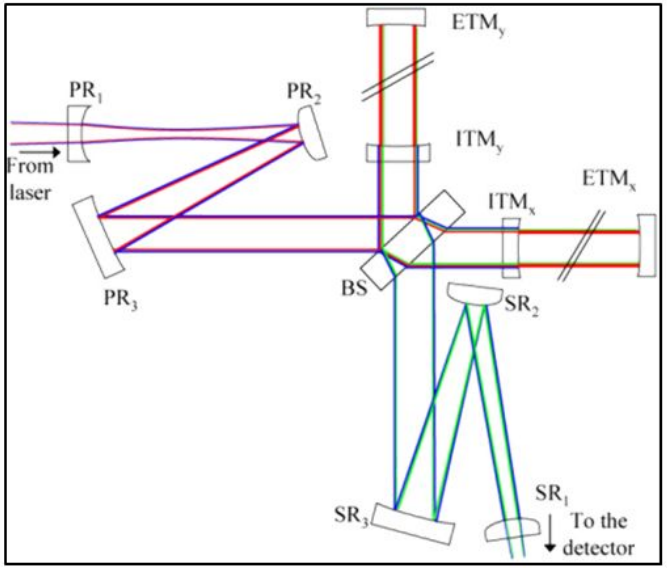
Beam expanding telescopes in existing detectors

- Advanced Virgo



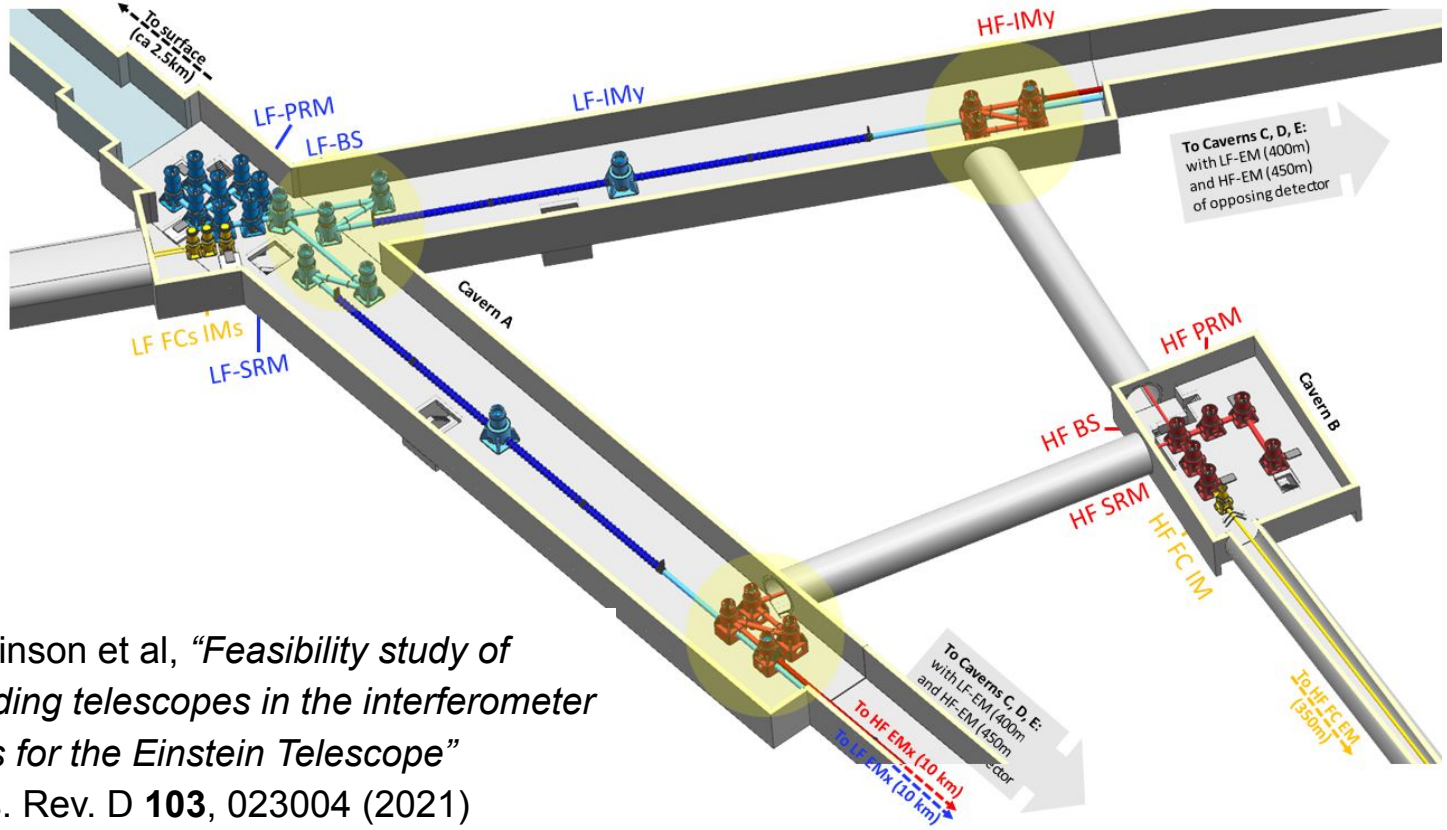
E. Genin et al, Class. Quantum Grav. 34 (2017) 095011

- Advanced LIGO



M. A. Arain and G. Mueller, Opt. Express 16, 10018 (2008)

Proposal for ET telescope



S. Rowlinson et al, *"Feasibility study of beam-expanding telescopes in the interferometer arms for the Einstein Telescope"* Phys. Rev. D **103**, 023004 (2021)

Advantages of the z-configuration

- Beam size on ET main mirrors are larger than in Adv-LIGO or Adv-Virgo: this would require a **very large substrate for the BS** because of the 60° AOI (i.e. > 120cm diameter for ET-HF)

  Having the telescope between the BS and the arms allows to keep small the beam size on BS, and also on the recycling mirrors (PRM and SRM) → smaller BS, PRM, SRM.

	ET-HF	ET-LF
ITM/ETM diameter	62 cm	45 cm
Beam radius on ITM/ETM	12.0 cm	9.0 cm

- Having a telescope for each arm allows to fine tune in a differential way the beam matching to the arms and optimize the interferometer visibility, if no other compensation systems are foreseen

A possible drawback for ET-HF

Target beam size @BS = **6mm**

- **Should be ok for LF, where circulating power in the Recycling cavity is ≈ 65 W**
- **Worrying for HF, where circulating power in the Recycling cavity is ≈ 11 kW**

↓

Thermal lensing in the BS substrate

↓

Higher-order modes excitation and interferometric visibility reduction

The discussion about the telescope z-configuration involves many work packages:

- Telescope mirrors will be suspended. How good should their seismic noise mitigation be not to affect longitudinal and angular noise performance?

- Will telescope mirrors need additional alignment signals for longitudinal and angular position of each mirror to be controlled?

- How much will the control noise affect the longitudinal noise budget?

Suspension design

Active noise mitigation

IFO sensing and control scheme

The discussion about the telescope z-configuration involves many work packages:

- How stringent are the requirements on the telescope optics quality for scattered light not to be detrimental for the interferometer visibility?

Core(?) optics

Scattered light

- Is the small beam size on BS (6mm) acceptable for ET-HF?
- For HF telescope, will the high circulating power induce aberrations on the parabolic mirrors themselves which must be actively corrected?

Wavefront sensing and control

- If yes, do we need additional optical benches to be installed around the telescope?

Infrastructures

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EXTRA SLIDES

Proposal for ET beam expanding telescope

S. Rowlinson, A. Dmitriev, A. W. Jones, T. Zhang and A. Freise

"Feasibility study of beam-expanding telescopes in the interferometer arms for the Einstein Telescope"

Phys. Rev. D **103**, 023004 (2021).