University of Glasgow

LSC advancedligo

Suspension Upgrades: Discussion Points + Questions

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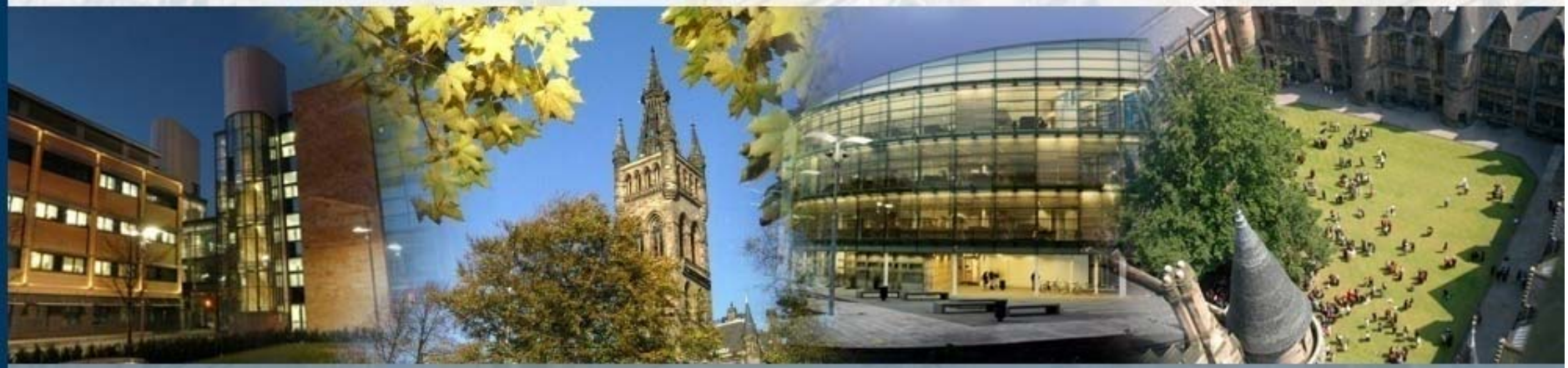


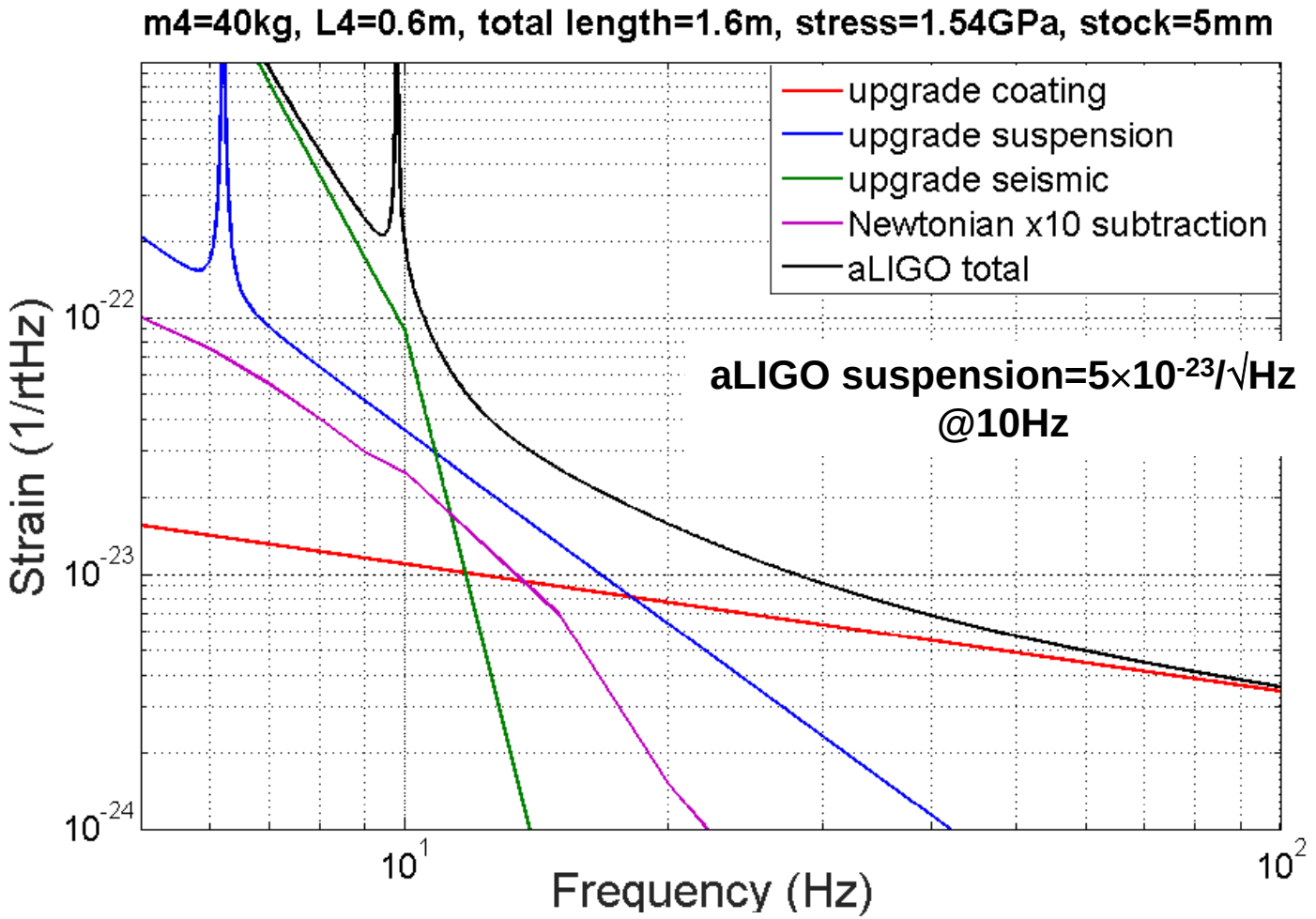
Overview

- Brief review of topologies
- R&D currently ongoing

Questions

- Longer + lower frequency: astrophysics rand/noise sources
- Modelling and Integration

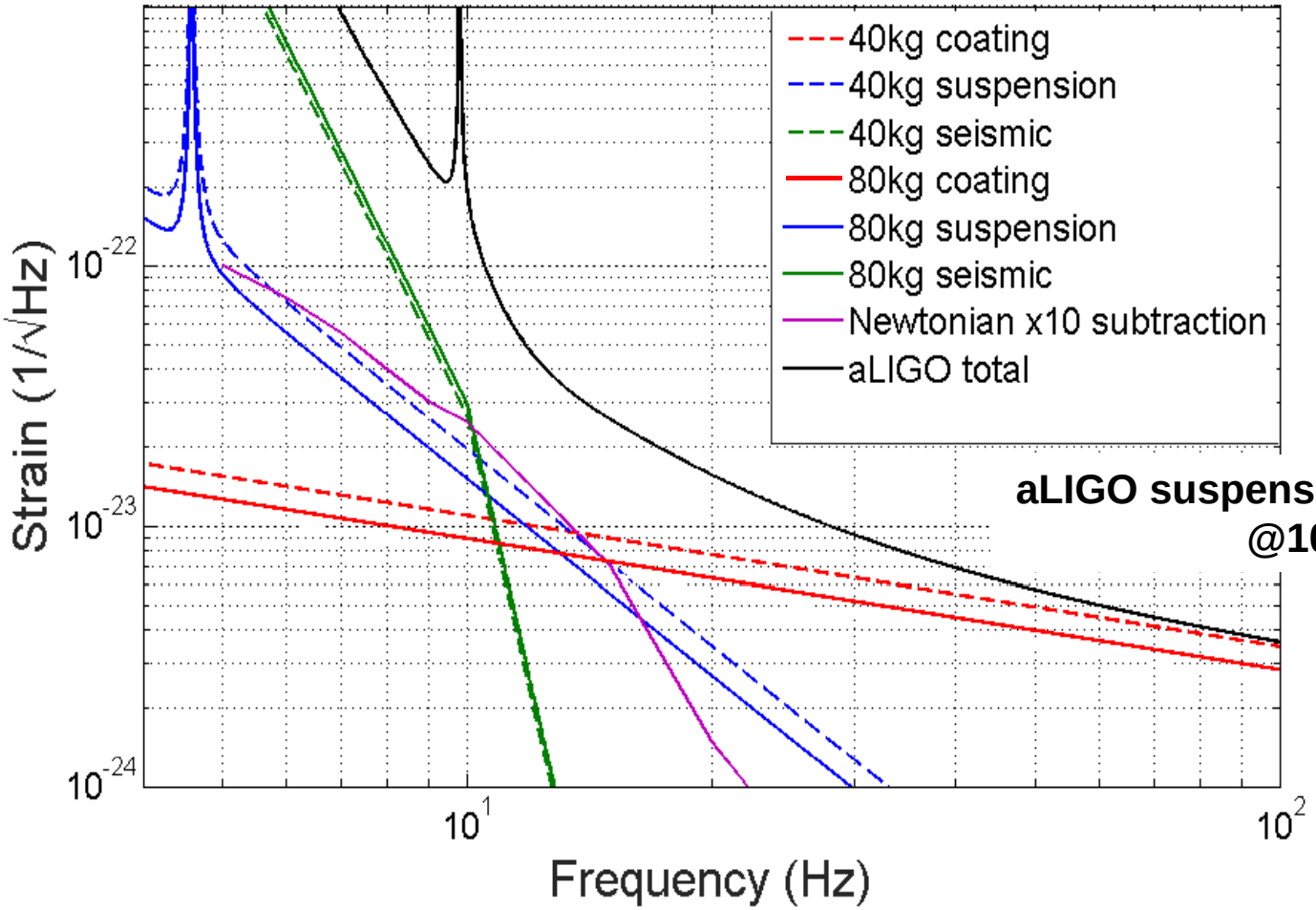
1. Higher Stress (>O1/A+)



- Minimal upgrade, only change final stage fibre geometry
- Ready by early 2016 with robustness testing (e.g. O1 upgrade or A+)

2. Longer Suspensions (A+, Explorer)

m4=40kg and 80kg, L4=1.1m, total length=2.14m, stress=1.54GPa, stock=5mm

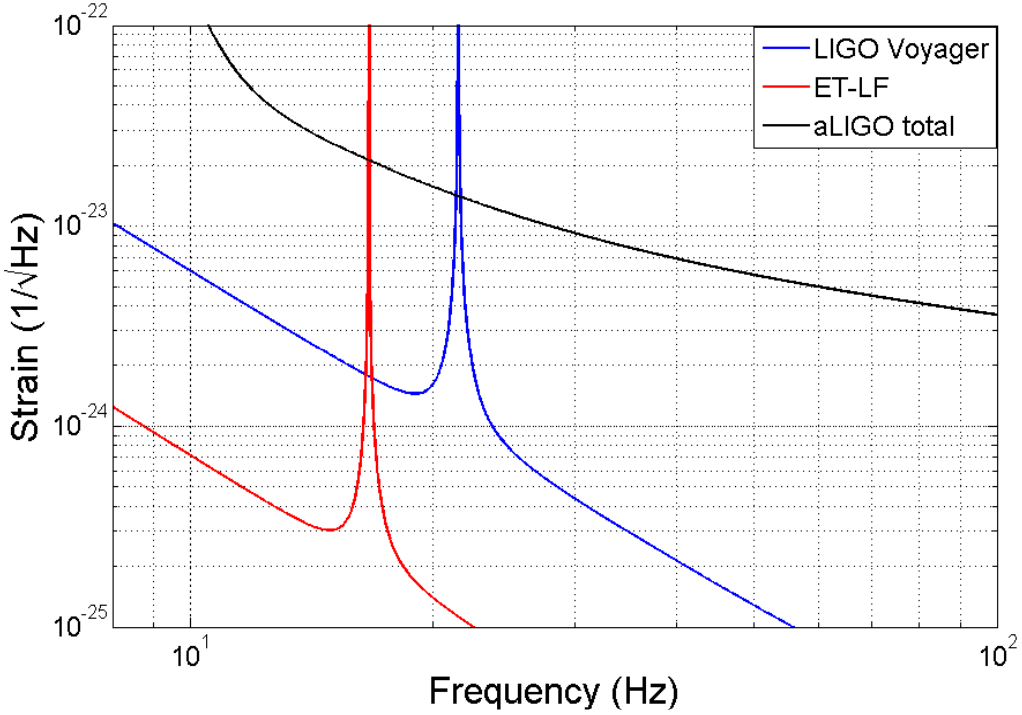


aLIGO suspension=$5\times10^{-23}/\sqrt{Hz}$ @10Hz

• Longer suspensions (final stage 1.1m) and higher stress offer further improvements for both 40kg and 80kg

3. Cold Suspensions (ET-LF/Voyager)

• Just showing suspension thermal noise for LIGO Voyager and ET-LF



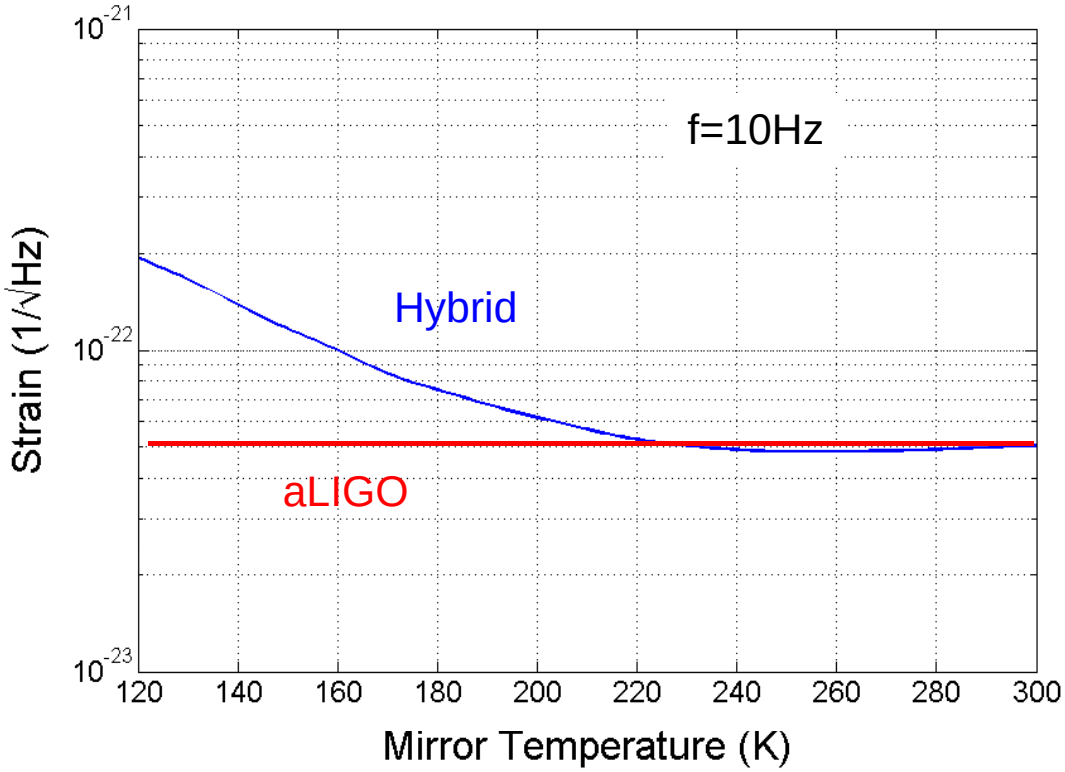
Parameter	Voyager	ET-LF
Geometry	Ribbon	Fibre
Power (MW)	3	0.018
L (m)	0.6	1
Mass (kg)	143	200
Test Mass (K)	124	20
Pen. Mass (K)	77	4
ϕ thermal (mm)	-	1
strength (mm)	2.5×0.5	ϕ1.5
Stress (Gpa)	0.3	0.3

• This is a **best case** as:
  – dilution will be lower for real ribbons/fibres (≈×2-3 when necks are included)
  – bond attachments and associated noise need to be included

=> community needs to work on robust modelling

4. Hybrid Suspensions

- Similar to aLIGO performance until 240K, but then worse performance than aLIGO



$$\phi_{\text{thermoelas tic}} = \frac{YT}{\rho C}\left(\alpha - \sigma_o \frac{\beta}{Y}\right)^2 \left(\frac{\omega\tau}{1+(\omega\tau)^2}\right)$$

- aLIGO uses thermoelastic cancellation to meet 10Hz requirement
- For cold silica, need to increase fibre diameter to maintain cancellation=> dilution gets worse
- T<240K, thermoelastic dominates until much lower temperature=> this pushes up thermal noise
- Challenges also with jointing materials with different CTE=>induced stress

- see talk by Marielle van Veggel (bonds)

Summary of Topologies

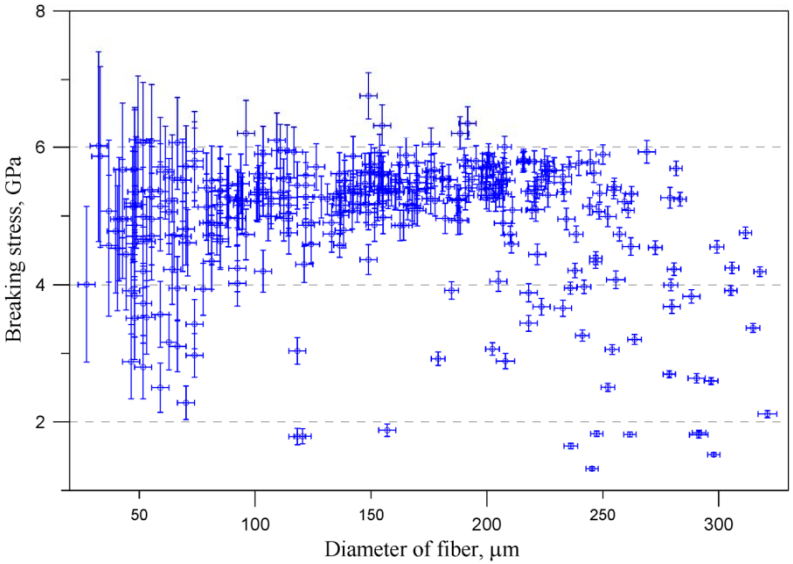
- There are a variety of suspension topologies which improve thermal noise performance

Parameter	High stress (e.g. A+)	Longer suspension (e.g. A+, Explorer)	Cold suspension (e.g. Voyager)	Hybrid suspension
10Hz improv.	×1.25	×2-3	×8 (Voyager), ×60 (ET-LF)	Not better than ×1.04
Hardware changes	None	modest-significant	significant	significant
Bounce mode	6Hz	5Hz	21Hz	6Hz
Violin mode	680Hz	370Hz	300Hz	680Hz
Stress	1.5GPa	1.5GPa	350MPa(1)	1.5GPa
Readiness	<1 year	≈2-3 year	≈3-5 years	≈3-5 years

- (1): grown fibre tensile stresses will likely be higher
- To understand full benefit need to include quantum noise and Newtonian noise

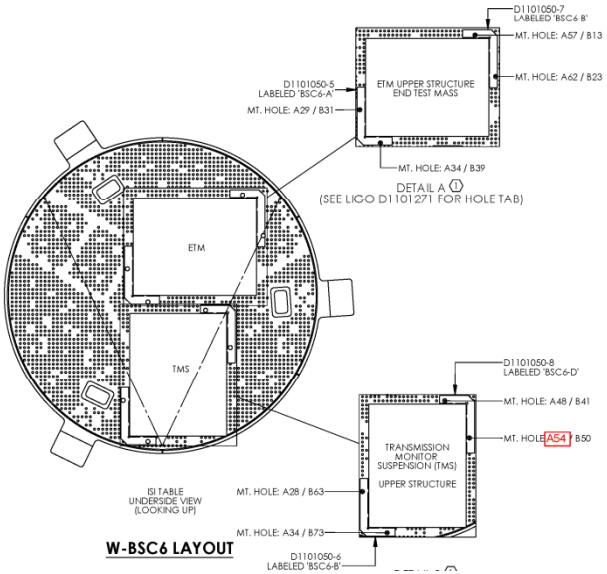
R&D

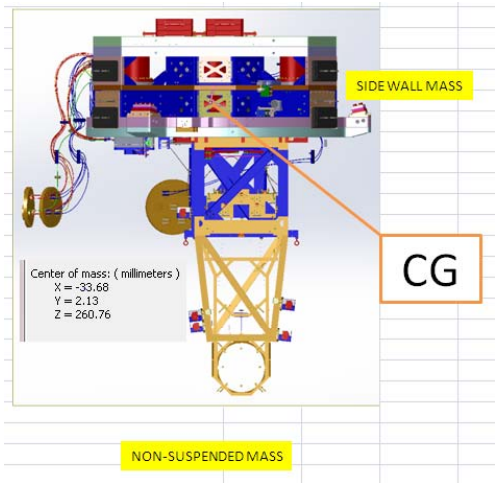
- Techniques to pull, weld and robustly test fused silica at higher stress
- Large scale test mass facility (up to 160kg)
- Springs of fused silica to lower vertical thermal noise
- Techniques to grow crystalline fibres
- Breaking test of silicon ribbons
- Tests of crackle noise

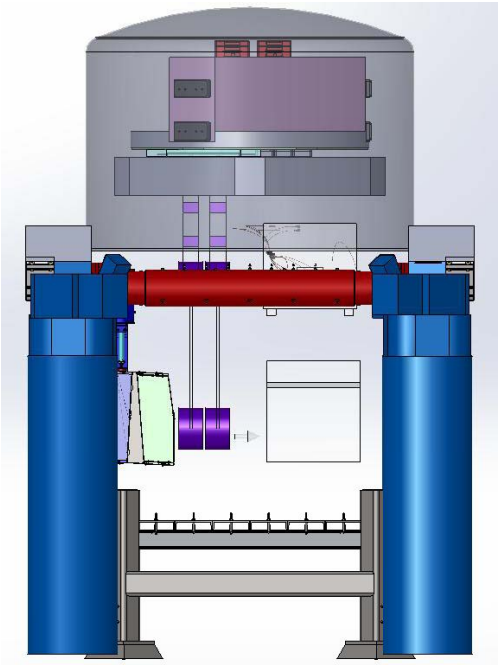


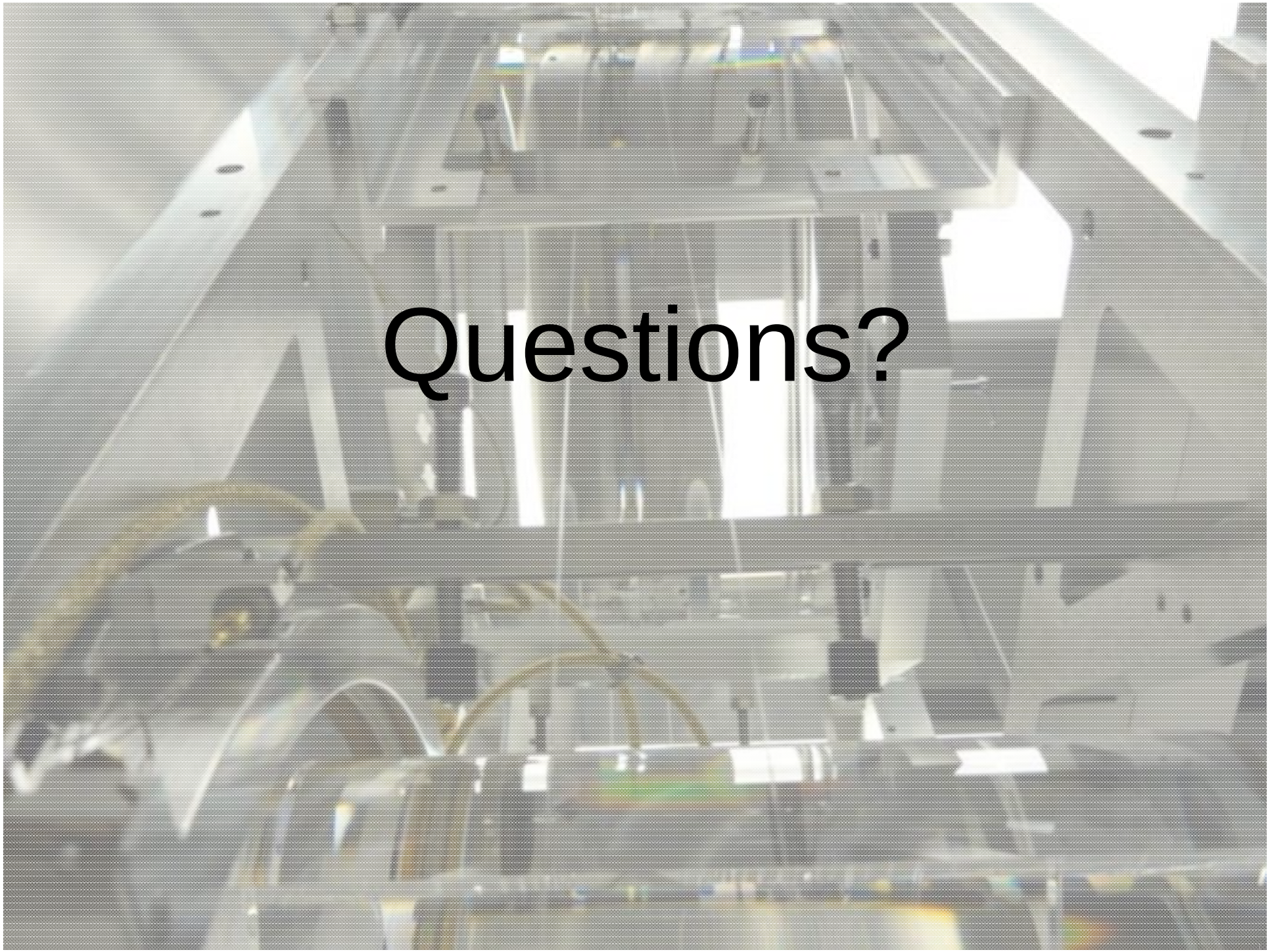
R&D

- Further characterisation of aLIGO suspension performance (LASTI and/or sites)
- Work with ISI team on better low frequency models, possible incremental improvements to ISI
- 80kg tests and longer suspension will require some modest re-engineering. Need to understand full implication via some case studies (e.g. ETM started)








Questions?

Longer + Lower Frequency

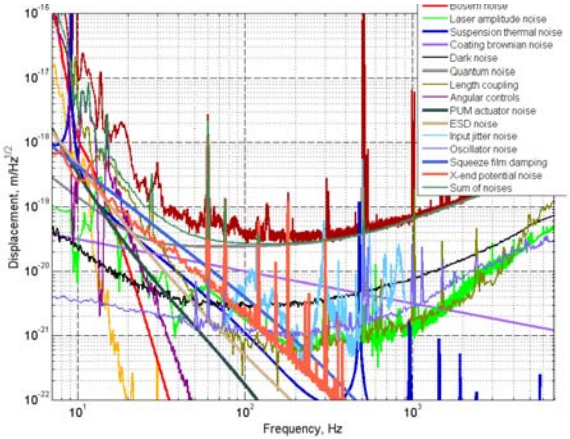
- Longer suspension push to lower operational frequency (depends on other noise source reduction) and also lower bounce/roll modes
- The time in band is

$$f_{GW} = \frac{1}{\pi}\sqrt{\frac{GM}{4R_0^3}}$$

$$\tau_{merger} = \frac{5}{32}\frac{R_0^4 c^5}{G^3 M^3}$$

$$\Rightarrow \frac{\tau_{merger1}}{\tau_{merger2}} = \left[\frac{f_{GW2}}{f_{GW1}}\right]^{8/3}$$

x2 longer when moving from 10Hz to 7.8Hz



- Astrophysics motivation depends on:
  - type of sources observed (NS-NS or BH binaries)
  - SNR build-up due to longer in time integration
  - longer trigger times for low latency searches (e.g. GRB's)

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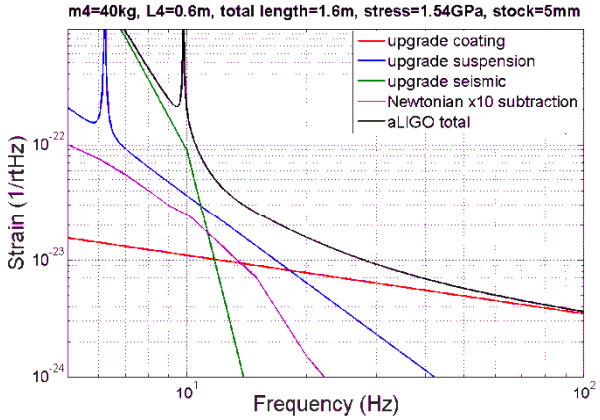
Longer + Lower Frequency

- Gaining low frequency benefit requires several noise sources to be tackled

- Newtonian subtraction
- Seismic noise
- Suspension thermal noise



- What other noise sources and considerations:
  - technical noise sources, better local control, better sensors (shadow/interferometric)
  - optimisation of local control with longer suspensions
  - optimum frequency of suspension modes (pitch-longitudinal coupling)
  - seismic improvements at low frequency
  - available height in chamber
  - installation and extraction techniques (e.g. cartridge install)
  - springs for additional vertical isolation

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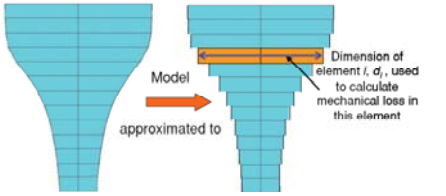
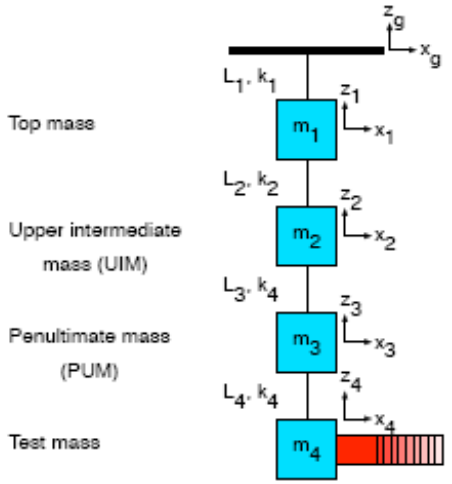
Modelling

- There are range of analytical and FEA codes out there for seismic and suspension estimation
- It seems sensible to use the IS working groups as a forum for the design of new suspensions, estimating their performance and developing necessary engineering solutions.





- Is there sufficient collaboration between the different groups
- What other codes are needed (GWINC_upgrade)
- Models at the early stage DO NOT correctly model dilution or the effect of fibre attachments via bonds. This is essential to develop most robust estimates
- What is appropriate feedback mechanism from the measurements made at LASTI/LIGO sites to inform future

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