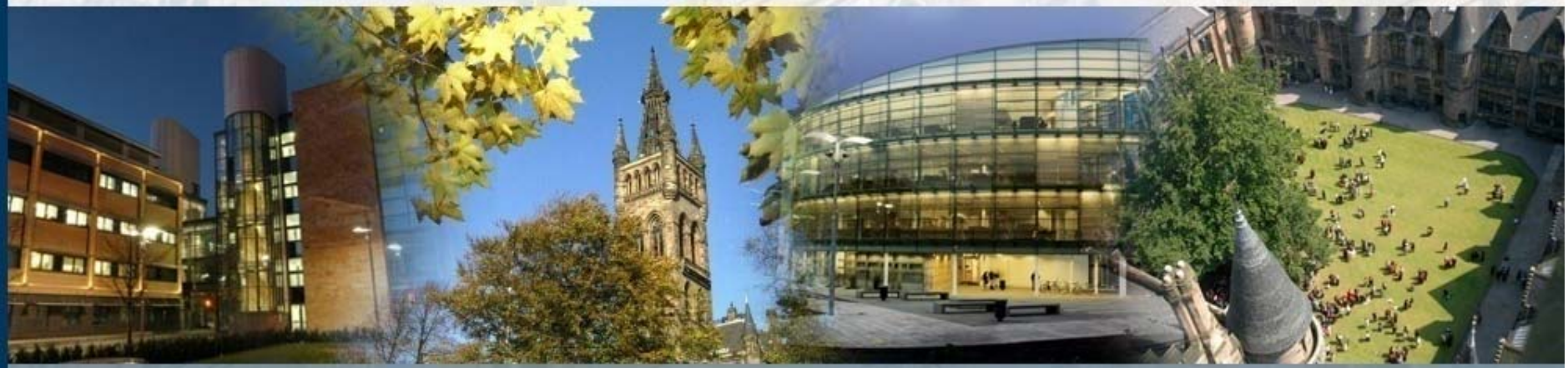
Suspension Upgrades for Enhanced Interferometers

Giles Hammond (Institute for Gravitational Research, SUPA University of Glasgow)



Overview

- Motivation for warm and cold suspensions
- Noise terms
- Some possible topologies
  - Higher stress aLIGO suspensions
  - Longer warm suspensions (40kg -80kg)
  - Cold upgrade scenarios
  - Hybrid suspensions
- Summary

Motivation for Suspension Upgrades

Warm upgrades (e.g. A+, ET-HF, Cosmic Explorer)

- Fused silica
- 80kg - 160kg test masses
- 60cm - 120cm suspension lengths
- 800MPa – 1.5GPa stress in fibres

Cold upgrades (e.g. LIGO Voyager, ET-LF)

- Silicon at 20K - 120K
- 143kg/200kg test masses
- 60cm/100cm suspension lengths

OPEN ACCESS
IOP Publishing
Made open access 4 February 2014
Classical and Quantum Gravity
Class. Quantum Grav. **31** (2014) 025017 (16pp)
doi:10.1088/0264-9381/31/2/025017

Silicon mirror suspensions for gravitational wave detectors

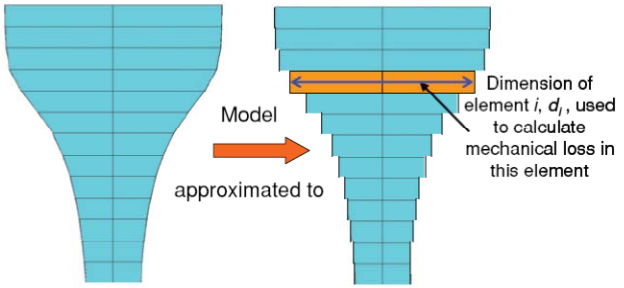
A V Cumming[1,4], L Cunningham[1], G D Hammond[1], K Haughian[1], J Hough[1], S Kroker[2], I W Martin[1], R Nawrodt[2], S Rowan[1], C Schwarz[3] and A A van Veggel[1]

- Warm upgrades with fused silica offer a well developed technology and improvements in strain sensitivity at low frequency of up to 3.
- Cryogenic upgrades for LIGO Voyager offer potential improvements in strain sensitivity of ≈8.

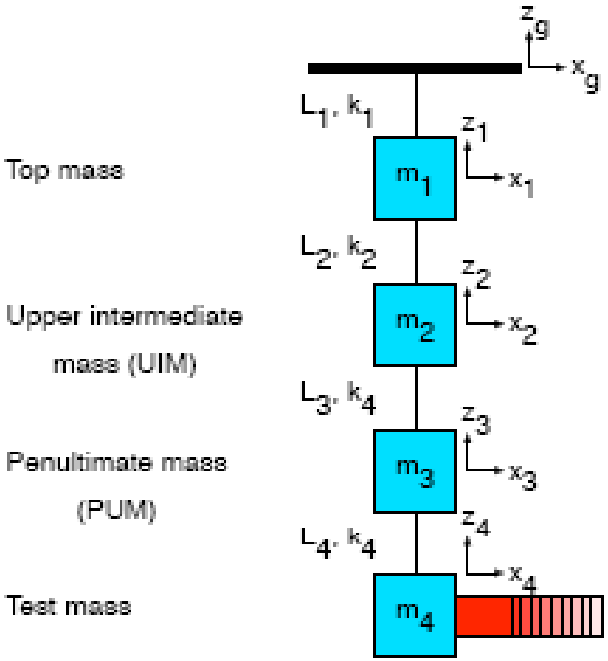
A V Cumming et al 2014 Class. Quantum Grav. **31** 025017
G D Hammond et al 2012 Class. Quantum Grav. **29** 124009

Noise Terms

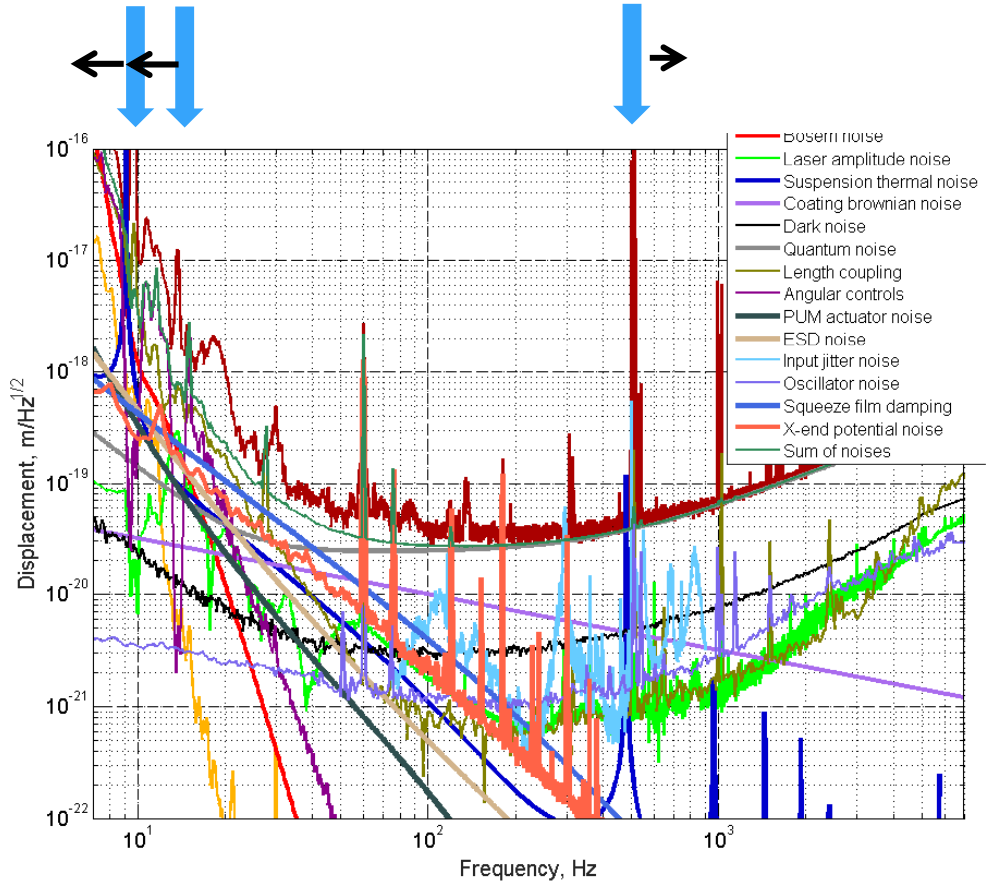
- **Suspension thermal noise**
  - uses a combination of analytical and FEA dilution
  - horizontal, vertical and violin thermal noise
- **Coating thermal noise**
  - uses finite test mass correction (Somiya and Yamamoto, Phys. Rev. D 79, 102004, 2009
  - optimised aLIGO coatings (16×131nm Ta_2O_5 and 17×182nm SiO_2)
- **Seismic Noise**
  - uses DCC note by Shapiro et al. (T1300786) to estimate transmissibility (longitudinal and vertical)
  - uses BSC requirements for ISI seismic noise (actually slightly better at 10Hz)



$$\frac{x_4}{x_g} = \frac{g^4}{(2\pi f)^8} \frac{1}{L_1 L_2 L_3 L_4} \frac{(m_1+m_2+m_3+m_4)(m_2+m_3+m_4)(m_3+m_4)m_4}{m_1 m_2 m_3 m_4}$$



1. Higher Stress (>O1/A+)



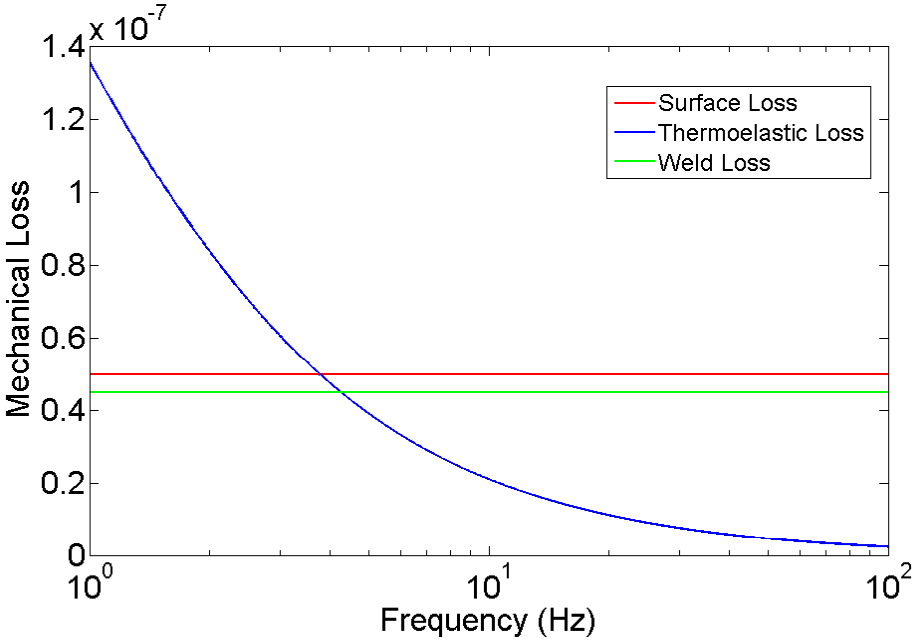
• LLO alog: posted 18:59, Wednesday 29 April 2015 - last comment - 07:14, Thursday 30 April 2015 (17946)

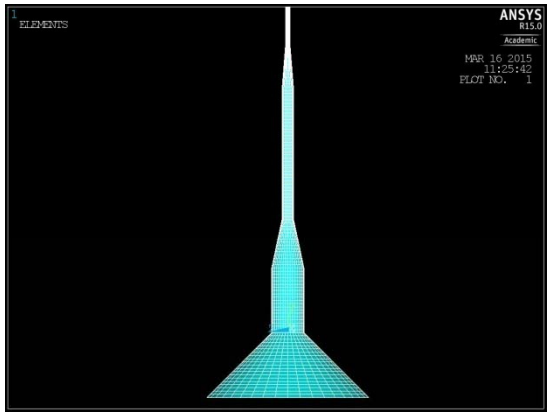
• Keeping current aLIGO test suspension geometry, and operating at 1.5GPa would push bounce/roll to 6Hz/9Hz, and violin modes to 680Hz

A Heptonstall et al 2014 Class. Quantum Grav. **31** 105006

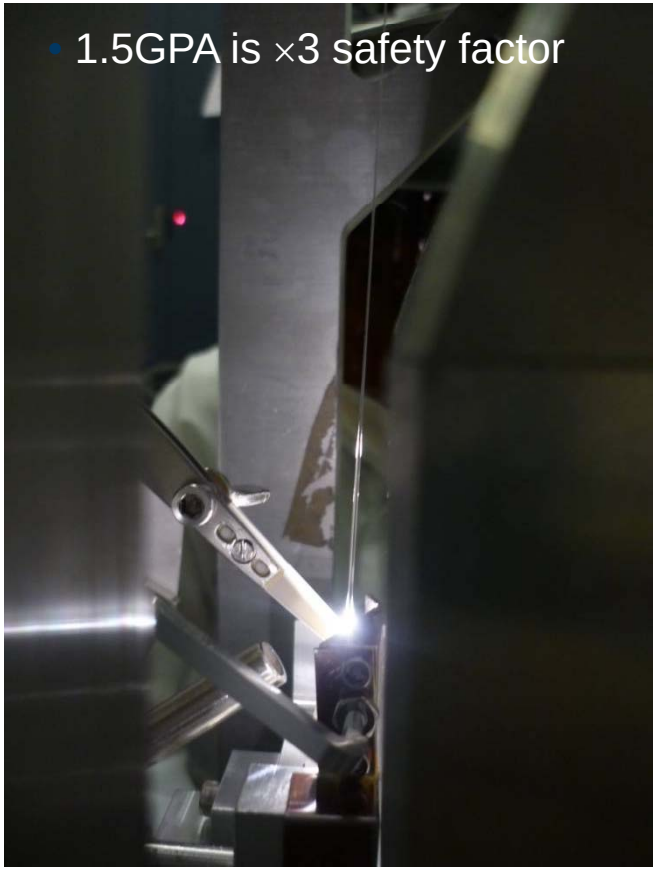
1. Higher Stress (>O1/A+)

• Keep end section at 800μm, but thin middle section to 300μm (1.5GPa). Use 5mm stock to improve dilution.





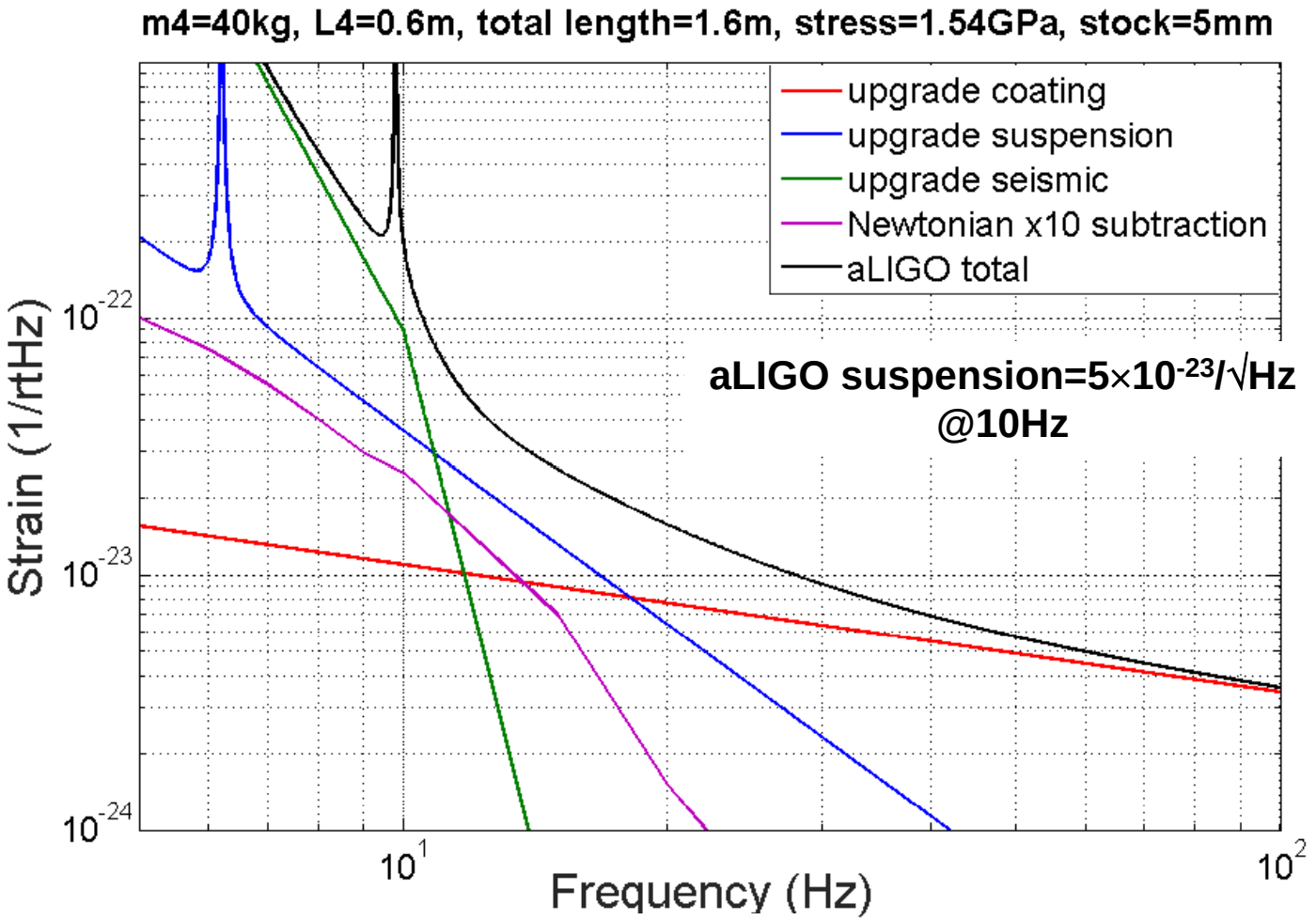
• 1.5GPA is ×3 safety factor



• 350μm suspension (1.1GPa) demonstrated at LHO during aLIGO SUS weld training (April 2015)

A Cumming et al 2009 Class. Quantum Grav. 26 215012

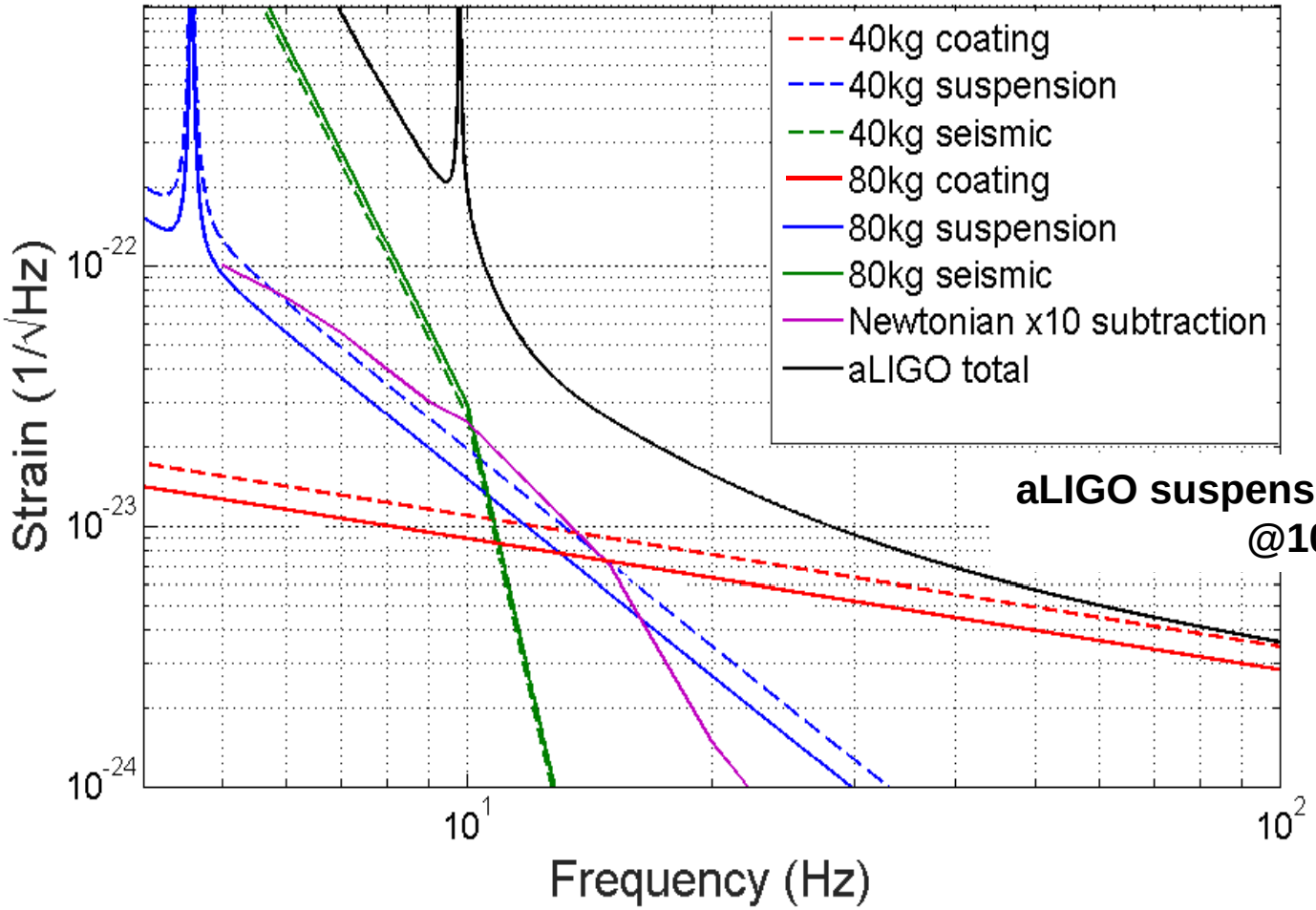
1. Higher Stress (>O1/A+)



- 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



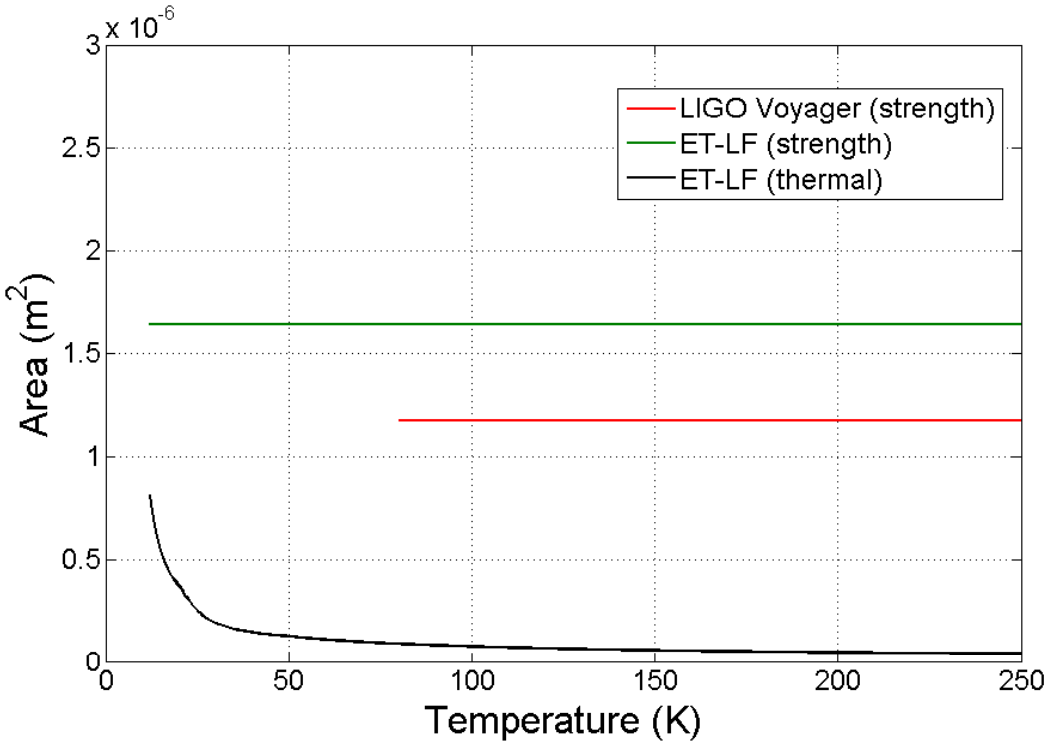
aLIGO suspension=$5\times10^{-23}/\sqrt{Hz}$ @10Hz

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

3. Cold Suspensions (ET-LF/Voyager)

LIGO Voyager assumes radiative cooling

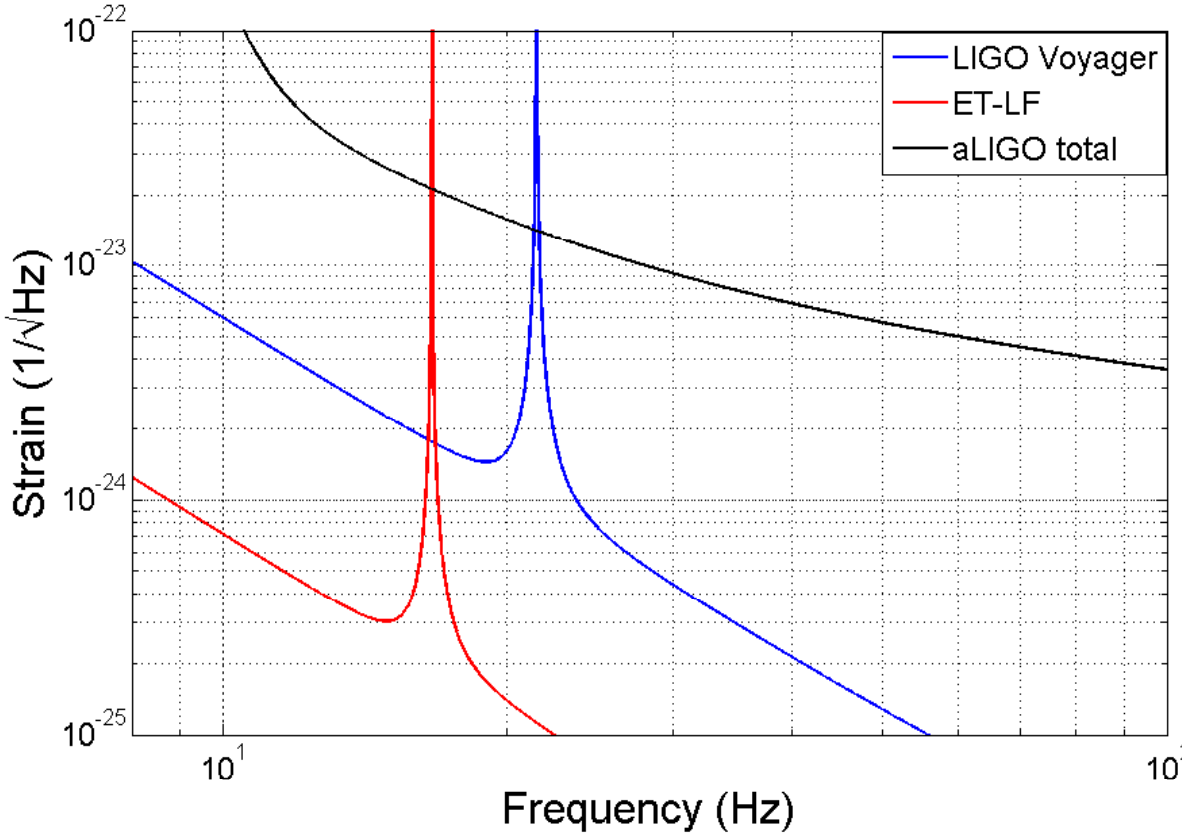
ET-LF assumes conduction cooling



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

3. Cold Suspensions (ET-LF/Voyager)

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

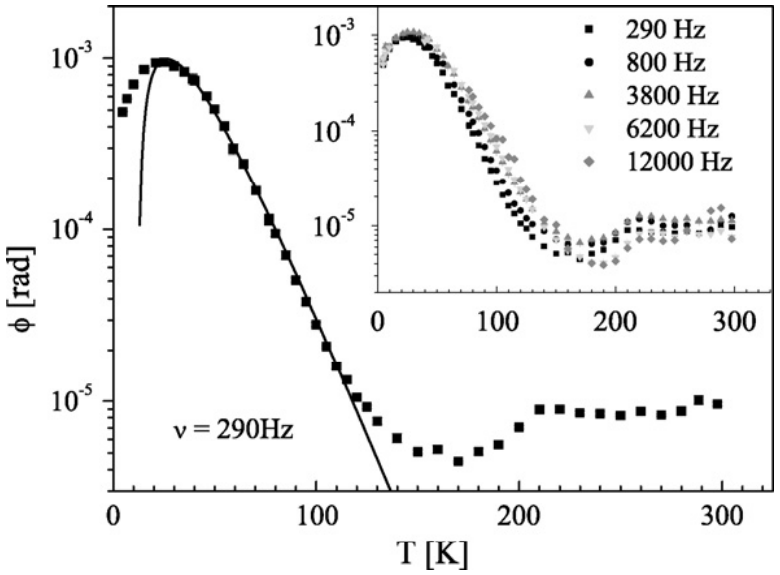


- This is a **best case** as:
  - dilution will be lower for real ribbons/fibres (≈×2-3 when necks are included)
  - bond attachments and associated noise need to be included

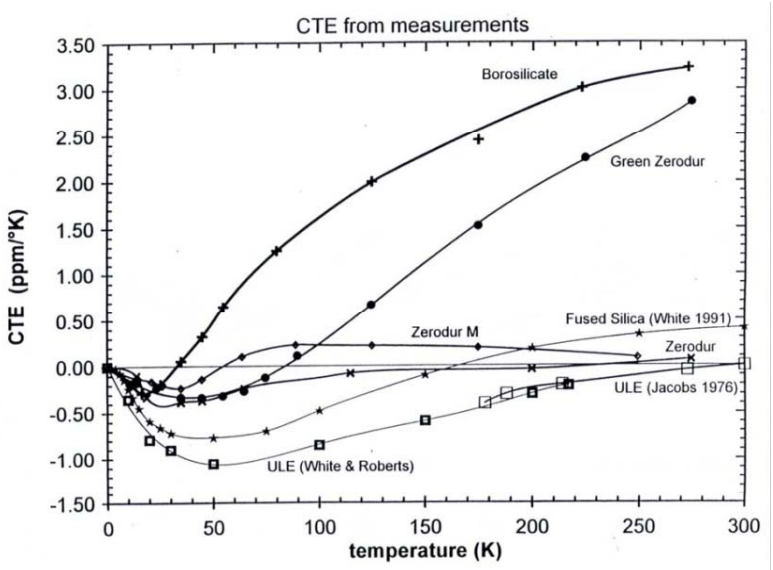
=> community needs to work on robust modelling (more discussion in breakout session)

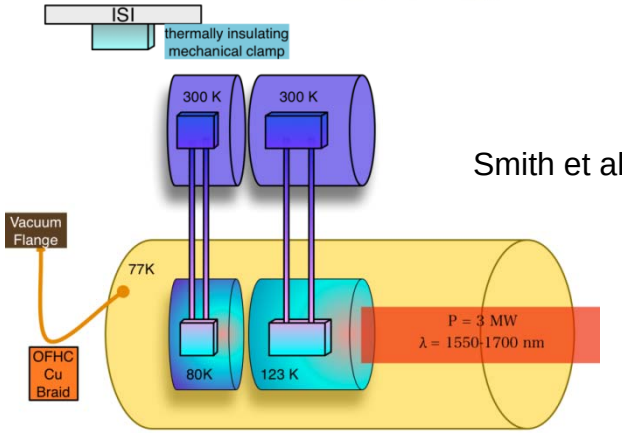
4. Hybrid Suspensions

- Hybrid suspensions are those which utilise silica fibres but with a silicon test mass (e.g. G1500312-v1)
- Silica has broad dissipation peak at low temperature. But can you still benefit from lower temperature operation



- Travaso et al., Materials Science and Engineering A 521–522 (2009) 268–271

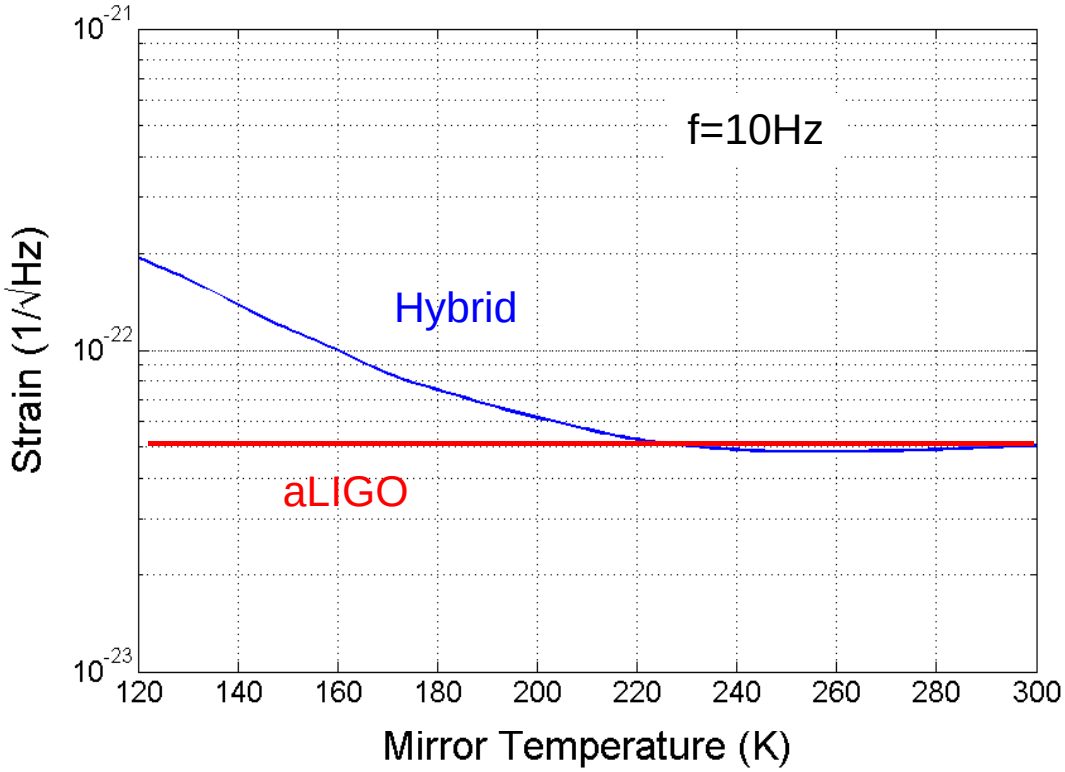




Smith et al., G1500312

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 (breakout session)

Summary

- 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