ARC Centre of Excellence for Gravitational Wave Discovery

OzGrav High Frequency Detector – Detector Design

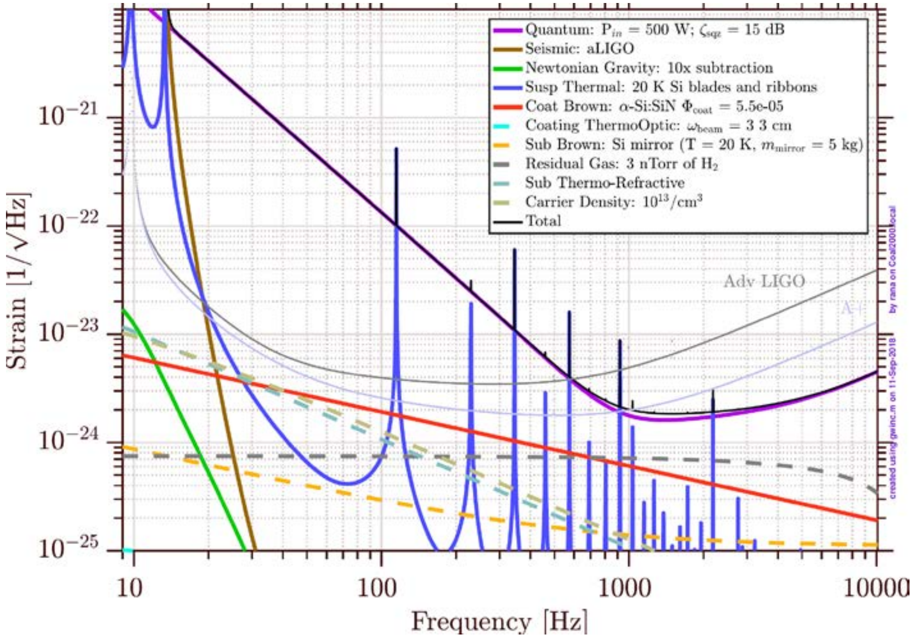
David Ottaway for HF Working Group

Introduction

- Detector design progress to date
- Critical Issues
  - Coating Thermal Noise
  - Interferometer Length
  - High Circulating Power
  - Cryogenics

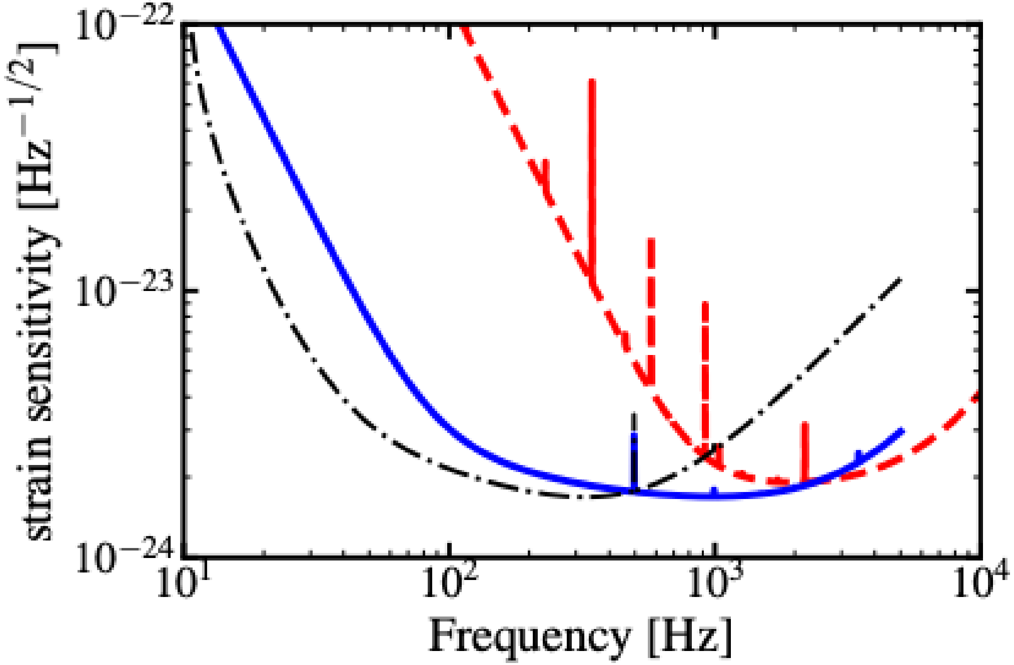
The detector

- How can we build a detector that is fundable that can make a real difference to the global network?
- Noise sources at HF generally simpler – mainly a light measurement problem
  - ie displacement noise sources not so important
  - Length not as critical – can be achieved by folding
  - Require extremely high power though (5 MW)
- Building a vacuum system from scratch give us advantage
- Cost \$50 M - \$100 M less may be more fundable



Proposed GEO HF Detector Noise Prediction, Denis Martynov et al.

Why we should focus on just HF



Cheap and Effective

- Really stiff suspensions prevent Siddles Sigg Instabilities
- Can use powerful actuators for length/alignment control with high bandwidth
- Significant folding to reduce length of vacuum pipes
- Minimal commissioning time

Low Frequency adds significant cost and complexity

- Displacement noise sources become important
- Auxiliary control noises become really important

Low Frequency Covered by three other longer detectors that have significantly bigger budgets – aLIGO+ and Virgo+

Key Issues

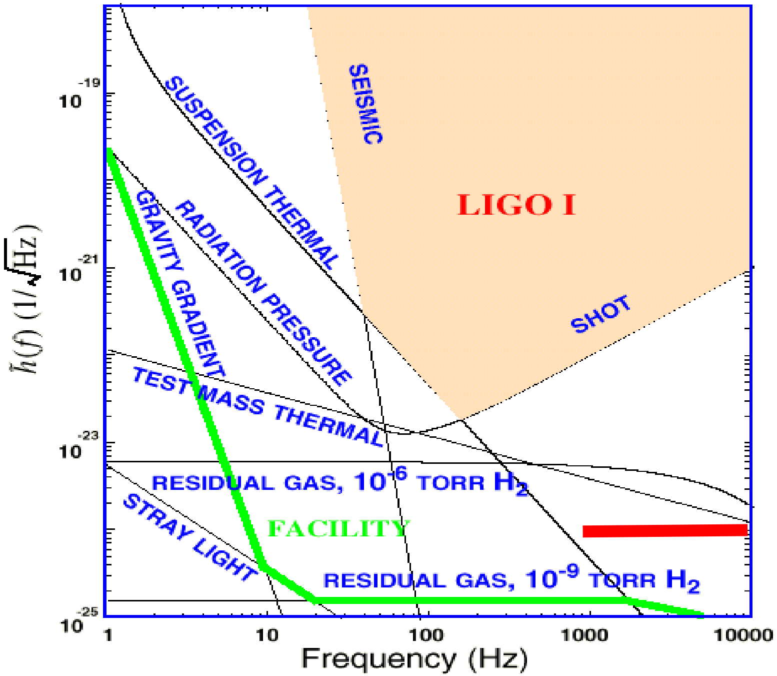
- Report on 23K vs 123K (TBD)
- OzMO Decision tree (David O, Rob W, Paul L and Eric T)
- Niobium suspensions or something else? (Joris and Peter V)
- Limitations from Kapitza resistance? (Joris)
- Signal recycling cavity very long cavity vs detuning (Dan B, Dave O and Rob W)
- Float zone silicon? (TBD)
- Suitable pipe diameter; pipe scaling laws (David B)
- Benefits/Risks of Folding (Dave O)
- Cost function (TBD)
- Risks with high circulating power
- Is laser frequency noise going to be an issue?

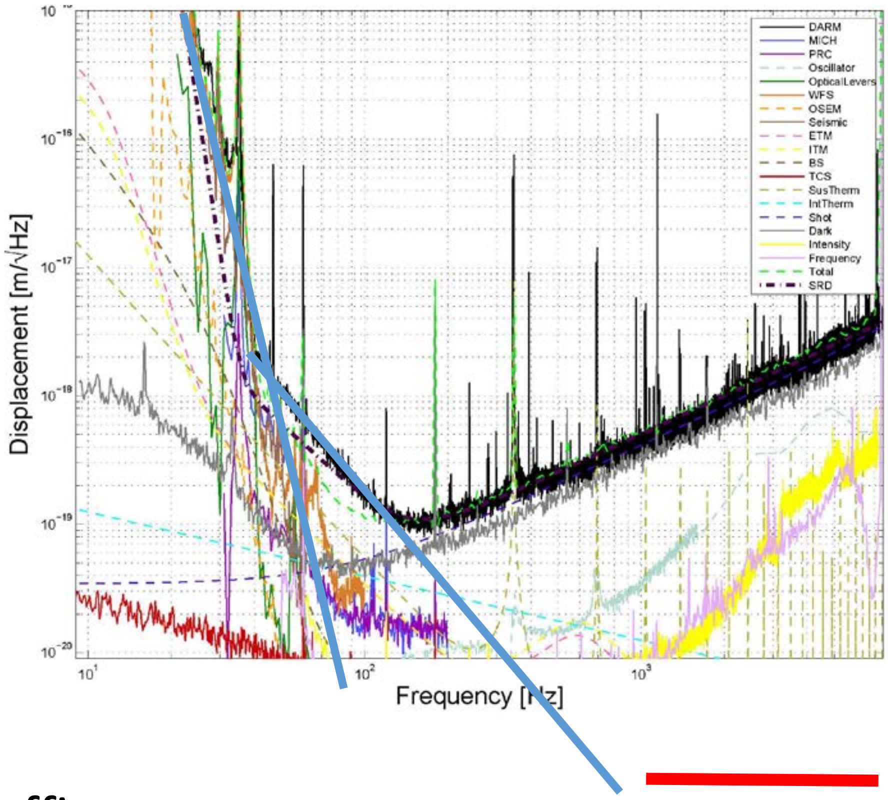
Design Studies/Talks to Date

- Initial Strawman Design given by Rob Ward
  - Virtuous cycle of going to 20k
  - Similar to Dan Martynov, 10 MW at 20 k
- Vacuum system discussion by David Blair
  - Need at least 1m diameter
  - Vacuum Pipe ~$2k/m => $4M for 1 km arm detector
- Suspension/Seismic Isolation by Joris van Heijningen
- Cryo materials by Joris van Heijningen/Peter Veitch
- Angular instabilities at high power by Liu Jian – Risk retired – just check noise
- Optimum test mass designs for minimising parametric instabilities by Zhang Jue,
- GW Polarization discussion by Paul Lasky
- Importance of HF by Paul Lasky
- Bilby/Pygwinc by Dan Brown

Beam Tubes Covers are important do we need them?

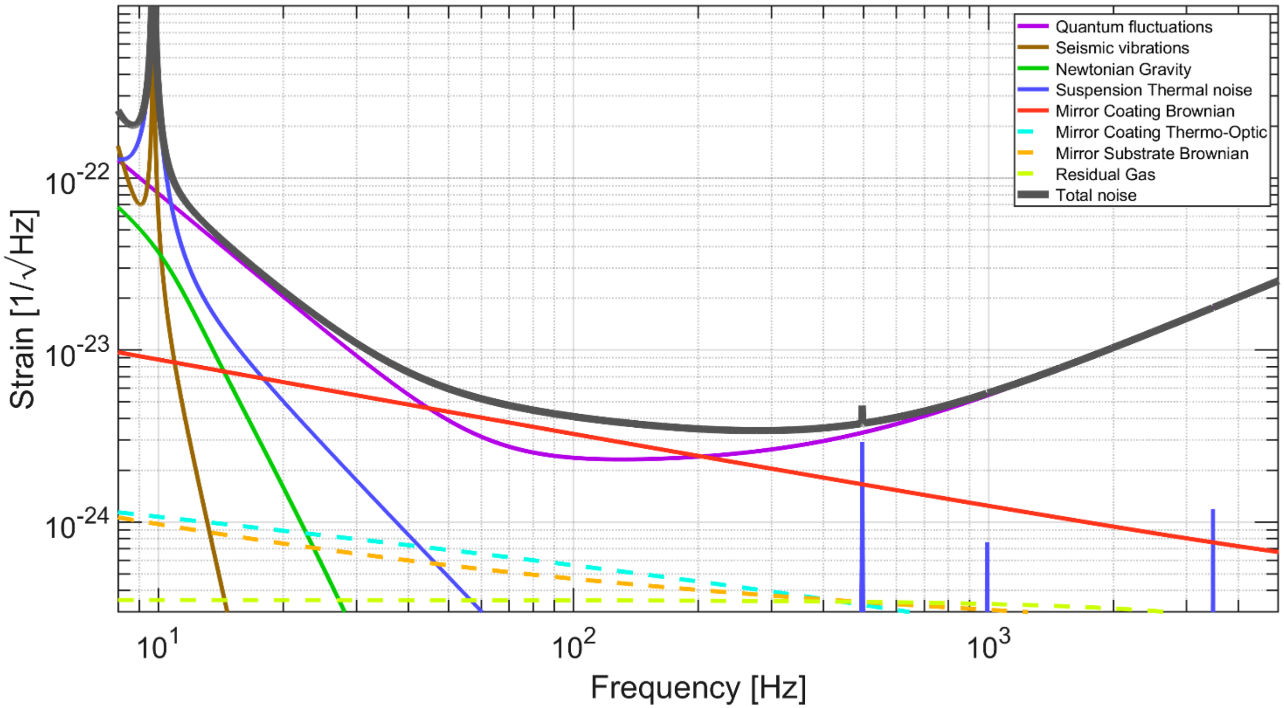
A perspective on HF Noise sources – Initial LIGO





- Large power actuators probably OK
- iLIGO Seismic and Suspension would suffice in Signal Band – Possibly not in control band

Thermal Noise for aLIGO

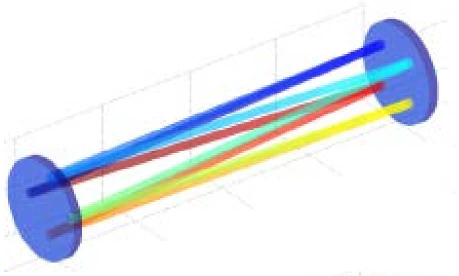


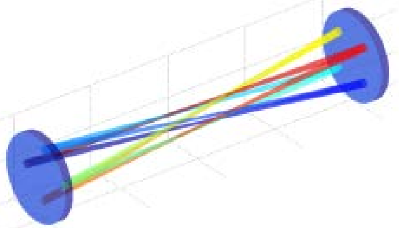
- Thermal noise in current aLIGO would almost suffice
- Can this be reproduced on kilometre scales ?
- Spot size scales $L_{arm}{}^{1/2}$
- Thermal noise scales
- $L_{arm}{}^{-1} Spot\ Size^{-1}$
- **But should be a test bed for LIGO Voyager technology**

A First Look of Folding OzGrav HF

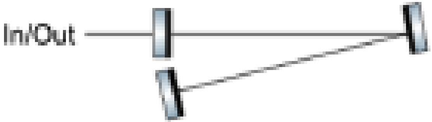
- Sensitivity in quantum noise dominated regime proportional to sqrt(Total Arm Length) – Regardless of Folding
- Coating Thermal Noise Scales inversely proportional to:

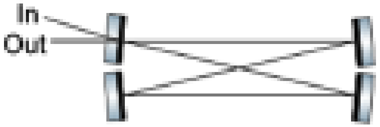
Spot size x bounce length x bounce factor





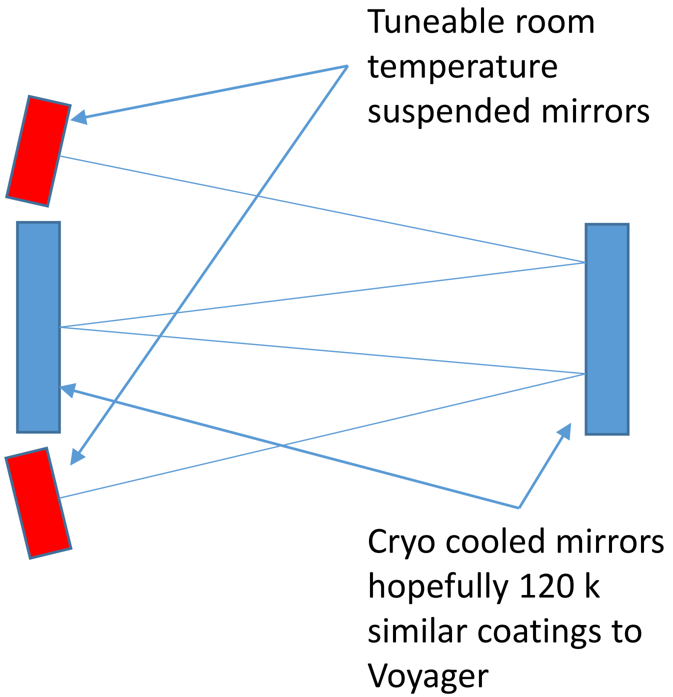
Parameter	Travelling Wave	Standing Wave
Spots per mirror	N_b	N_b
Total Reflections	$2N_b$	$4N_b - 2$
Round Trip Length	$2N_bL$	$(4N_b - 2)L$
Displacement amplitude thermal noise factor	$\sqrt{2N_b}$	$\sqrt{12N_b - 10}$
Thermal noise reduction factor	$\sqrt{N_b}$	$\dfrac{2N_b - 1}{\sqrt{N_b}}$
Quantum shot noise reduction	$\sqrt{N_b}$	$\sqrt{2N_b - 1}$





Proposed Folded Cavity for OzGrav HF

- Aim for a 16km long arm cavity
- Gwinc modelling “kluges”
  - All thermal noise put in Mirror
    - $\emptyset_{eff} = (\emptyset_{RT} + 12\emptyset_{CRYO}(N_{bounce}-1))/2$
  - Arm length:
    - $L_{eff} = L_{arm}(2N_{bounce} - 1)$
  - All relay losses put in ITM/ETM
    - $Loss_{ETM} = Loss_{HR}(N_{bounce} - 1/2)$
- Full 16 km sensitivity
- Silicon at 120 k has thermal expansion = 0
- Tuneable of optic mode on room temperature mirrors
- Back of envelope suggests $5 \times 10^{-25} Hz^{-1/2}$ at 1 kHz possible in 1km detector (is 500m possible?)
- Full modelling required



Possible Breakout Sections Topics

20K vs 123K ?

Benefits/Risks of Folding ?

What is the optimum vacuum length or how short can we get away with?

Parametric Instability Issues at 10MW - Solutions

Risks with high circulating power?

OzMO Decision tree