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
Why we should focus on just HF

Cheap and Effective
• Really stiff suspensions prevent Siddles Siggs 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 $L_{\text{arm}}^{-1}$
- Thermal noise scales $L_{\text{arm}}^{-1} \text{Spot Size}^{-1}$
- 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 $\sqrt{\text{Total Arm Length}}$ – Regardless of Folding

- Coating Thermal Noise Scales inversely proportional to:
  \[
  \text{Spot size x bounce length x bounce factor}
  \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Travelling Wave</th>
<th>Standing Wave</th>
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</thead>
<tbody>
<tr>
<td>Spots per mirror</td>
<td>$N_b$</td>
<td>$N_b$</td>
</tr>
<tr>
<td>Total Reflections</td>
<td>$2N_b$</td>
<td>$4N_b - 2$</td>
</tr>
<tr>
<td>Round Trip Length</td>
<td>$2N_bL$</td>
<td>$(4N_b - 2)L$</td>
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<tr>
<td>Displacement amplitude thermal noise factor</td>
<td>$\sqrt{2N_b}$</td>
<td>$\sqrt{12N_b - 10}$</td>
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<tr>
<td>Thermal noise reduction factor</td>
<td>$\sqrt{N_b}$</td>
<td>$\frac{2N_b - 1}{\sqrt{N_b}}$</td>
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<tr>
<td>Quantum shot noise reduction</td>
<td>$\sqrt{N_b}$</td>
<td>$\sqrt{2N_b - 1}$</td>
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Proposed Folded Cavity for OzGrav HF

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