Beyond Einstein: From the Big Bang to Black Holes

LISA Technology Development at NASA/GSFC

J.I. Thorpe

37th COSPAR Scientific Assembly
Montréal, Québec
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Outline

Laser Frequency Stabilization
- Optical Cavities with frequency tuning
- Molecular Iodine

Stable Environments
- Stable test-bed for formation flying
- Fused-silica fibers for torsion pendula

Surface Effects
- Kelvin Probe

Laser Study
Laser Frequency Stabilization
  - Optical Cavities with frequency tuning
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Laser Study
Laser frequency noise is a major potential noise source for LISA

- Three-stage system (two active one passive) to achieve overall suppression of $\sim 10^{13}$
- Running pre-stabilization and arm-locking in series reduces gain (bandwidth) requirements on arm-locking.
- Serial arrangement requires frequency-tunable pre-stabilization
Offset Sideband Locking

Concept: Lock phase-modulation sidebands to cavity resonance and tune central frequency by adjusting modulation frequency.

Normal Pound-Drever-Hall Lock

Sideband Lock

Thorpe, Numata, Livas
• Standard PDH and sideband locking have identical noise performance
• Common technical noises limit both systems.
• Adding modulation tone does not disturb the broadband noise floor.

Thorpe, Numata, Livas
Combining with Arm-Locking

- Simulate 1-s long arm using EPD technique
- Pre-stabilize laser using offset sideband locking technique
- Arm-Lock using sideband offset as frequency actuator

Thorpe, Mitryk, Wand
Arm-Locking Results

- Free-running and pre-stabilized lasers meet LISA requirements in band.
- Arm-locking system behaves as predicted. (noise spikes at n/τ frequencies)
- Progress towards demonstration of 2/3 of LISA frequency mitigation plan.
Spectroscopic reference provides Absolute reference frequency

Laboratory study of frequency stability using two independent Nd:YAG lasers stabilized to hyperfine transition in $I_2$

Slightly worse than cavities for $f > 1$ mHz

Better performance below 0.1 mHz
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Laser Study
Testing LISA’s inter-spacecraft interferometer on stable platforms

- 2 optical benches with 2 independent pre-stabilized lasers
  - Silicate bonded optical bench, heterodyne interferometer with phasemeter
- 2 degree-of-freedom active control
  - Intended to kill unwanted ground & thermal motion.
  - PZT-based hexapod provides actuation capability.
  - Noise suppression factor: 100~500
    - Performance limited by mechanical coupling from uncontrolled other 4 DoFs.

Displacement Noise [m/rtHz]

J.I. Thorpe
37th COSPAR Scientific Assembly – Montréal, Québec
For lowering fundamental noise limit of torsion pendulum

- **Our methodology**
  - Fiber puller, coater, pendulum for loss measurement
  - Thin coating technique development

**Significant advantages confirmed**

- **LISA requirement should be reachable with silica**
  - Test started in LISA torsion pendula in Univ. of Trento & Univ. of Washington

<table>
<thead>
<tr>
<th>Suspended mass [kg]</th>
<th>Acceleration Noise @ 1mHz [m/s^2/rtHz]</th>
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<tr>
<td>0.001</td>
<td>$10^{-11}$</td>
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<tr>
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<td>$10^{-14}$</td>
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<tr>
<td>10</td>
<td>$10^{-15}$</td>
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</tbody>
</table>

- **7um**
- **14um**
- **22um**

**Fiber puller**

**Fiber coater**

**Numata & Camp**

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Laser Study
 KP measurements of LISA gold surface

- Vibrating probe induces current proportional to surface potential
- KP limited by ADC quantization noise (recently upgraded)
- Excess low frequency voltage noise of gold surface measured with KP
- Magnitude barely OK for LISA, but cause unknown
- LISA Advantages for patch-effect problem
  - Gold coatings are non-reactive
  - Test mass kept at room temperature
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Laser Study
LGS Cost/Design Study of LISA laser

Testing of pump combiner

- optical characterization (insertion loss and PER stability) from 5 - 70 C
- thermal screening under high power in vacuum
- temperature cycling in air

J. Camp
Contributors

Jordan Camp
Volker Leonhart
Jeff Livas
Shawn Mitryk (GSFC/UF)
Kenji Numata
Ira Thorpe
Vinzenz Wand (UF)
Backup Slides
Three Flavors of Sideband Locking

Single Sideband (SSB)

- Simplest to implement
- Some noise coupling due to asymmetry

Dual Sideband (DSB)

- Restores PDH symmetry
- Complex modulation pattern

Electronic Sideband (ESB)

- Simple, symmetric modulation pattern
- Requires phase modulation capability on LO

\[ \Omega \]

\[ \Omega_1 \]

\[ \Omega_2 \]

PM

EOM

EOM1

EOM2

\[ \omega_c + \Omega \]

\[ \omega_c - \Omega \]

\[ \omega_c + \Omega_1 + \Omega_2 \]

\[ \omega_c + \Omega_1 - \Omega_2 \]

\[ \omega_c + \Omega_1 \]

\[ \omega_c + \Omega_2 \]
**Fundamental Noise**
- Shot noise
- Cavity thermal noise

**Technical Noise**
- Temperature Fluctuations
- Servo Noise
- Photoreceiver noise
- RIN
  - via RFAM
  - via absorption
- Vibration Noise/Acoustic
- Pointing
- ???

**Diagram:**
- The graph shows the spectral density $(S_{y}(f))^{1/2}$ plotted against Fourier frequency (Hz). The graph includes different noise components such as measured, thermal noise, shot (PDH), shot (SB), cav. temp, servo, RIN, and PR.
• Measured noise suppression matches expectations
• ~40dB at 100mHz