Beyond Einstein: From the Big Bang to Black Holes

LISA Technology Development at NASA/GSFC

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37th COSPAR Scientific Assembly
Montréal, Québec
July 16th, 2008
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
Outline

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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
**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.
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
• 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.

![Graph showing frequency response](image)

**Labelled Axis**:
- **Displacement Noise [m/rtHz]**
- **Frequency [Hz]**

**Legend**:
- Red: Freerun
- Blue: Stabilized (Heterodyne)
- Green: Stabilized (Homodyne with corner cube)
- Purple: LISA optical bench requirement
- Grey: Coupling from "shear" motion

**Graph Details**:
- Frequency range: 0.0001 to 100 Hz
- Displacement noise levels range from $10^{-12}$ to $10^{-5}$ m/rtHz

**Credits**:
- Numata & Camp
Silica Fiber for Force Noise Test

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

![Graph showing acceleration noise vs. suspended mass for different materials and fiber coating thicknesses.](image-url)

- **Fiber puller**
- **Fiber coater**

Numata & Camp

J.I. Thorpe
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Laser Study
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
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

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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
Fundamental Noise
  - Shot noise
  - Cavity thermal noise

Technical Noise
  - Temperature Fluctuations
  - Servo Noise
  - Photoreceiver noise
  - RIN
    - via RFAM
    - via absorption
  - Vibration Noise/Acoustic
  - Pointing
  - ???
• Measured noise suppression matches expectations
• ~40dB at 100mHz