LISA

Beyond Einstein: From the Big Bang to Black Hole

LISA Technology Development at NASA/GSFC

J.I. Thorpe

37^{th} COSPAR Scientific Assembly

Montréal, Québec

July 16^{th}, 2008

GSFC - JPL

esa

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

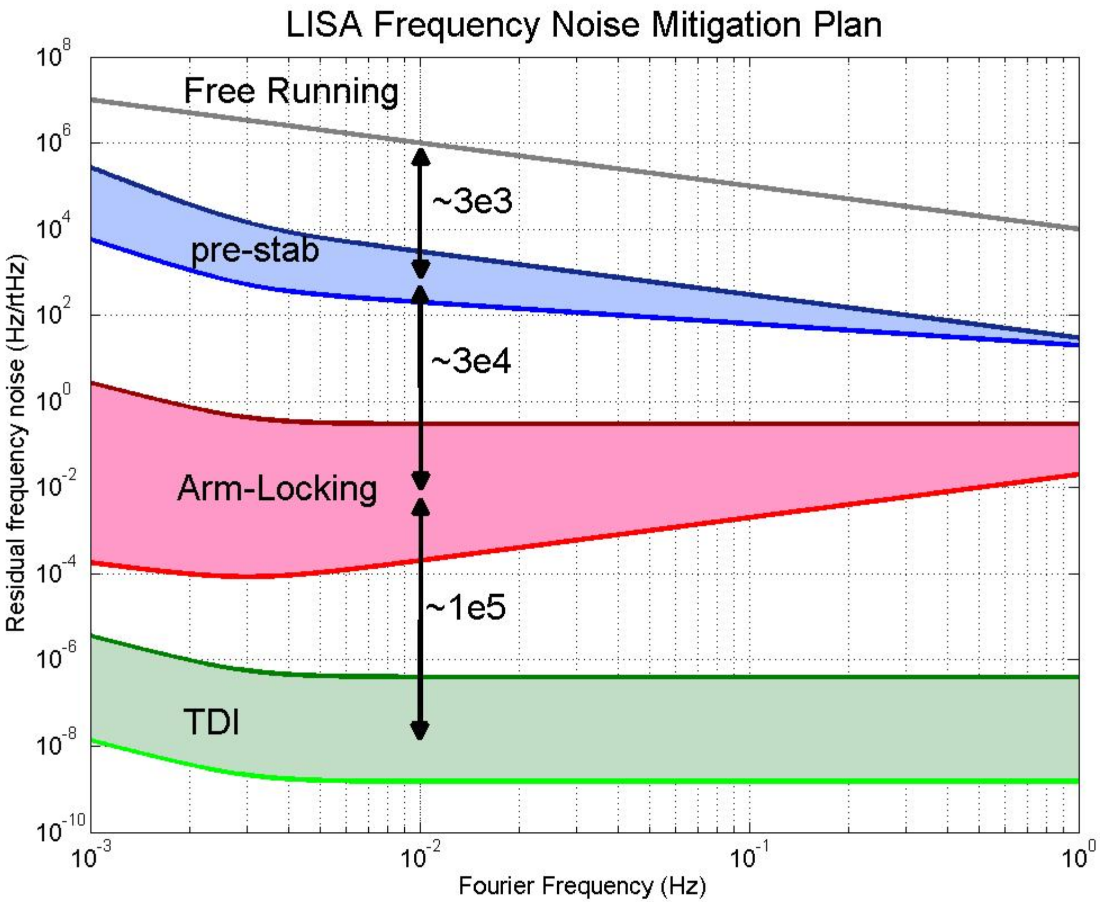
Outline

- 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 Noise in LISA

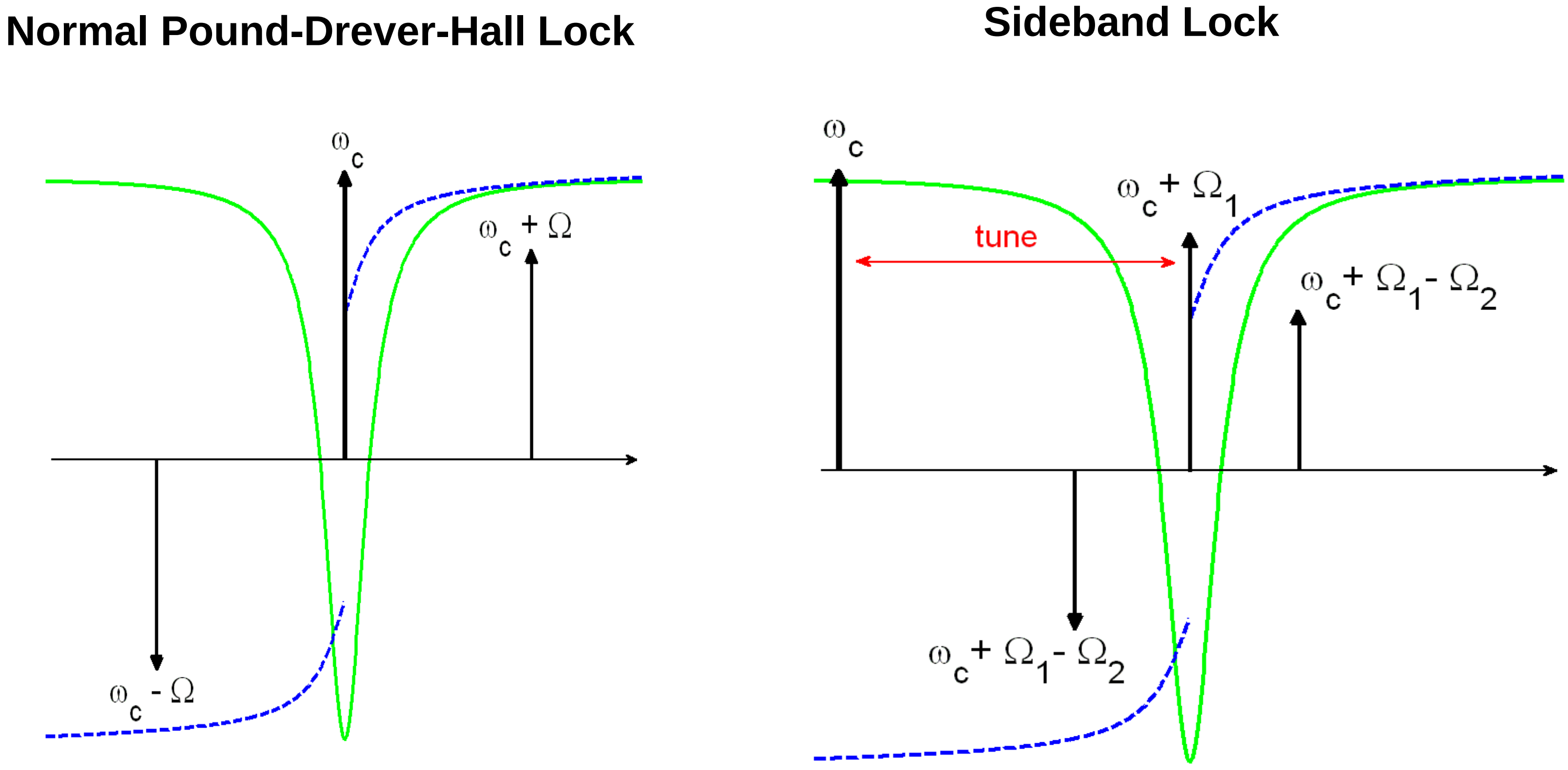
Laser frequency noise is a major potential noise source for LISA

- Three-stage system (two active one passive) to achieve overall suppression of ~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

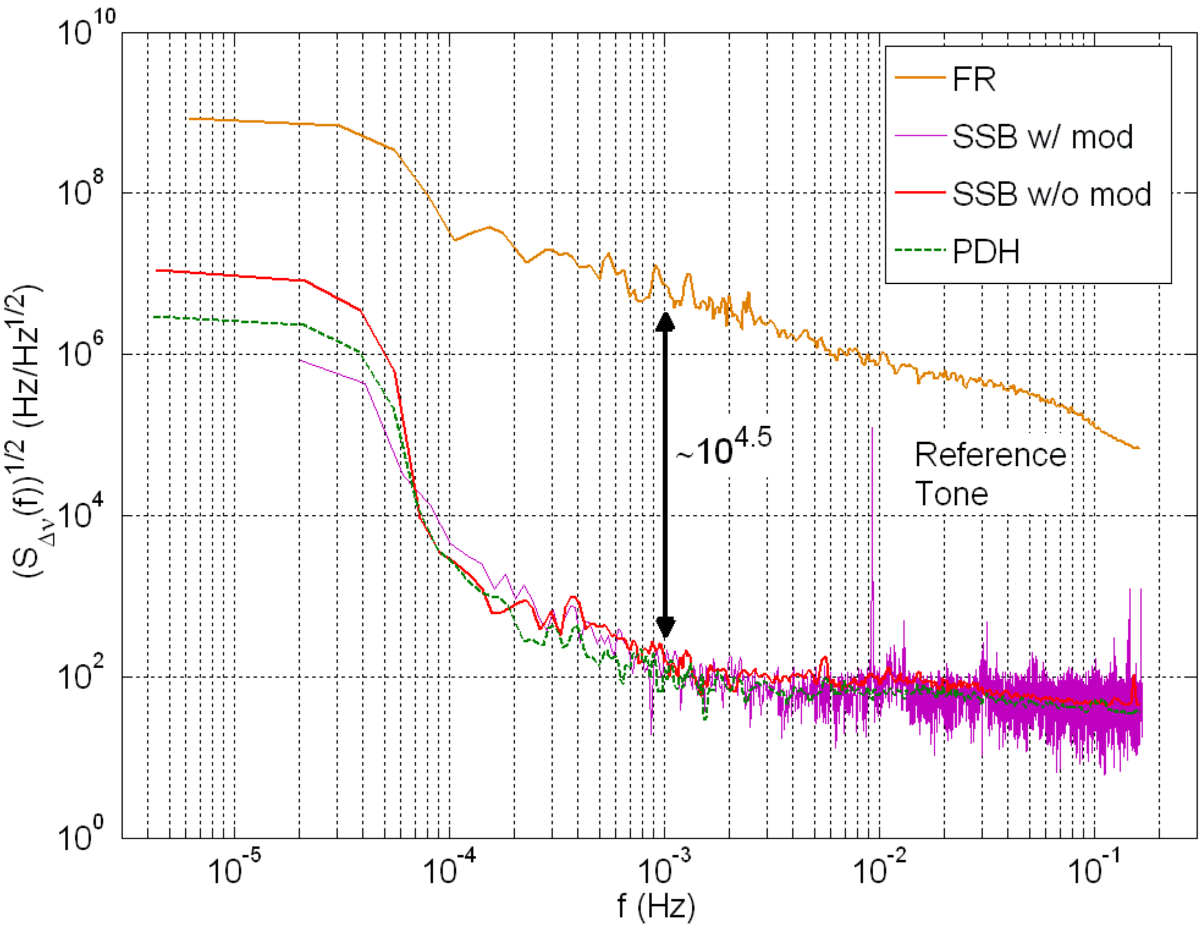
Concept: Lock phase-modulation sidebands to cavity resonance and tune central frequency by adjusting modulation frequency.



Thorpe, Numata, Livas

Offset Sideband Locking with Optical Cavity

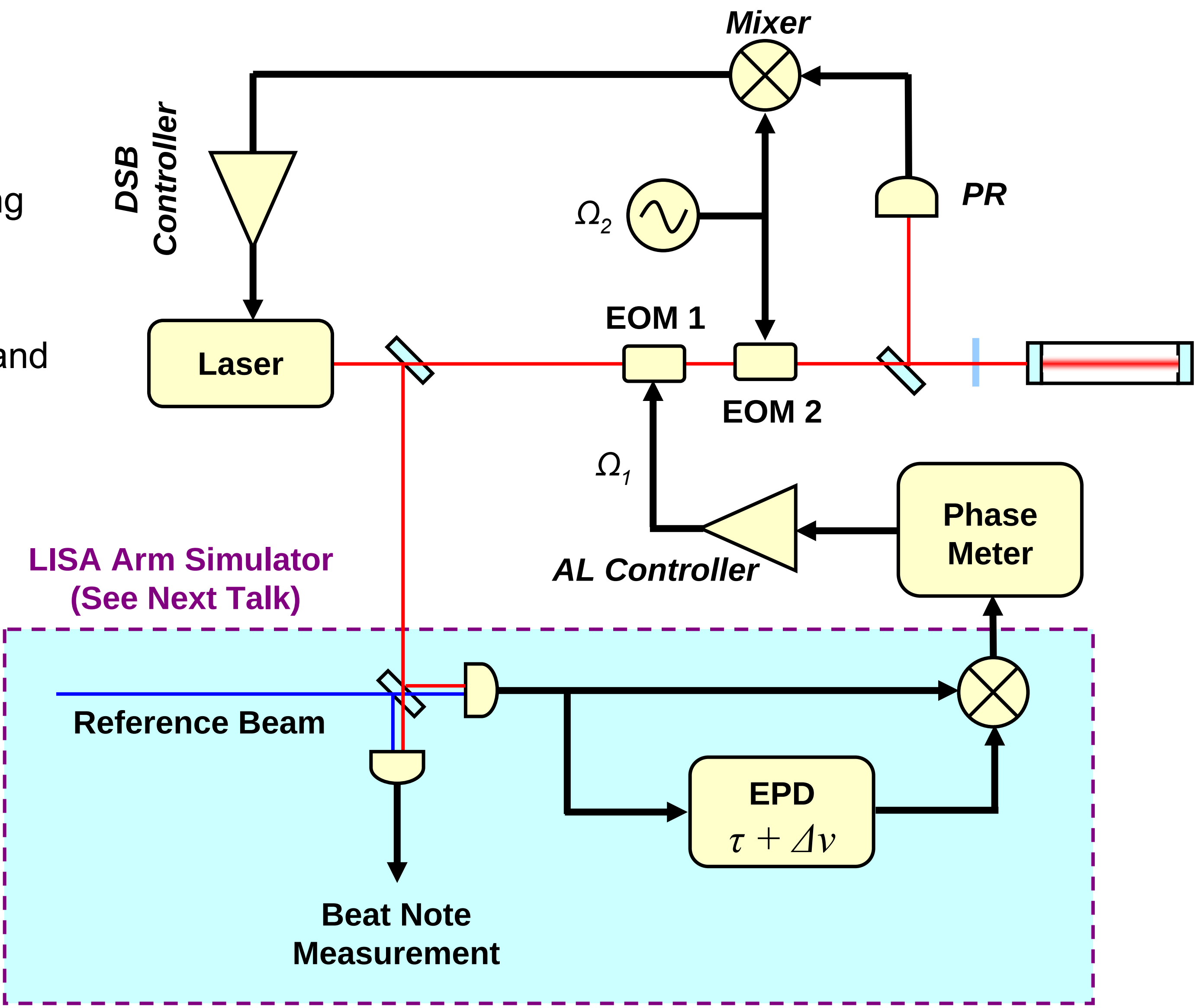
- Standard PDH and sideband locking have identical noise performance
- Common technical noises limit both systems.
- Adding modulation tone does not disturb the broad-band noise floor.



Thorpe, Numata, Livas

Combining with Arm-Locking

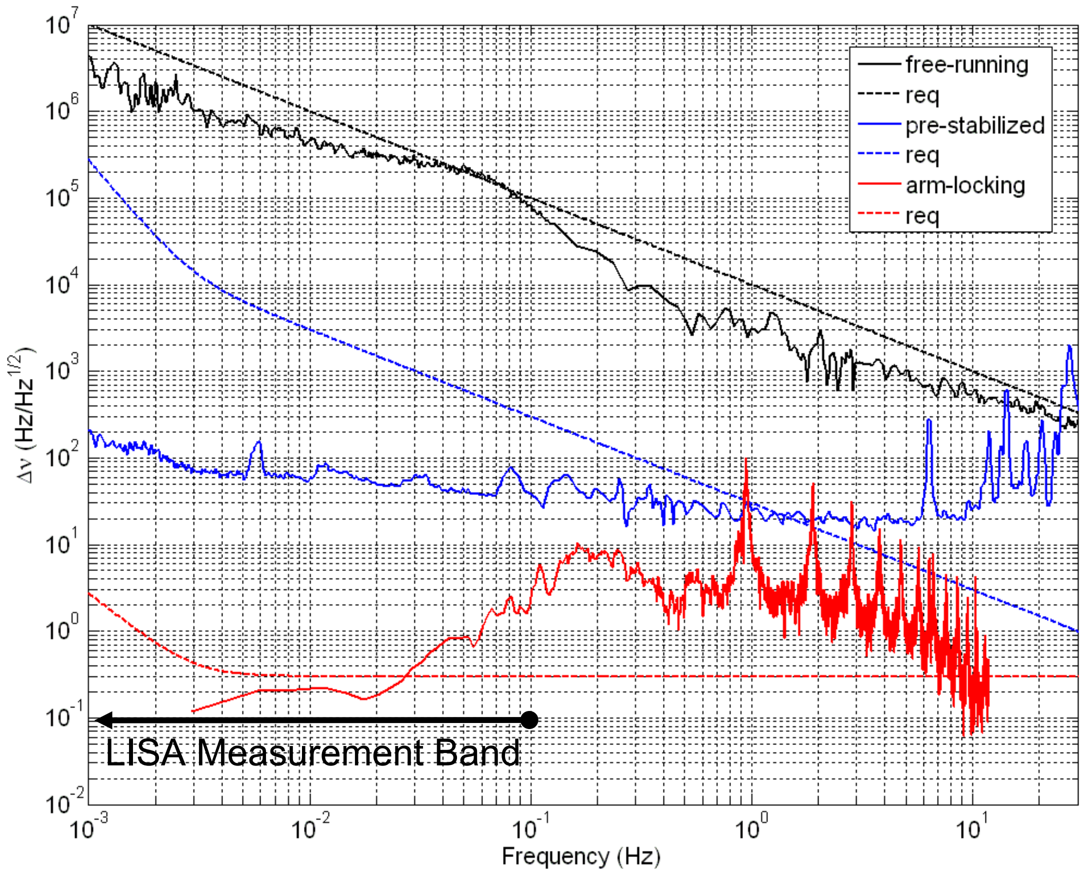
- Simulate 1-s long arm using EPD technique
- Pre-stabilize laser using offset sideband locking technique
- Arm-Lock using sideband offset as frequency actuator



Thorpe, Mitryk, Wand

Arm-Locking Results

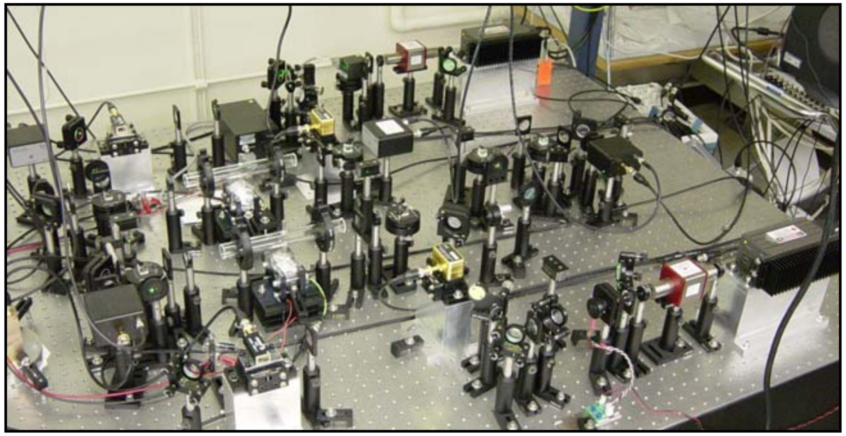
- Free-running and pre-stabilized lasers *meet LISA requirements in band*.
- Arm-locking system behaves as predicted. (noise spikes at n/τ frequencies)
- Progress towards demonstration of 2/3 of LISA frequency mitigation plan.

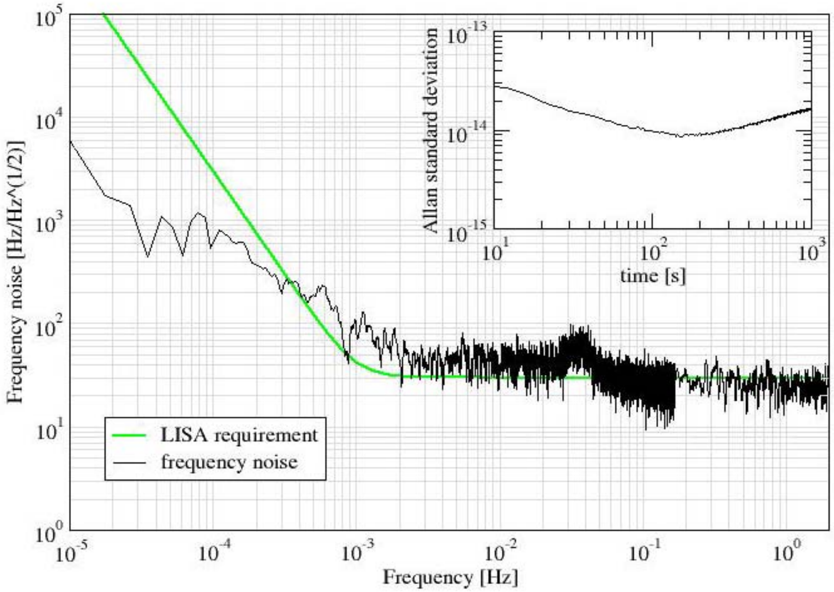


Thorpe, Mitryk, Wand

Iodine stabilization

- 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 > 1mHz
- Better performance below 0.1 mHz





Leonhart & Camp

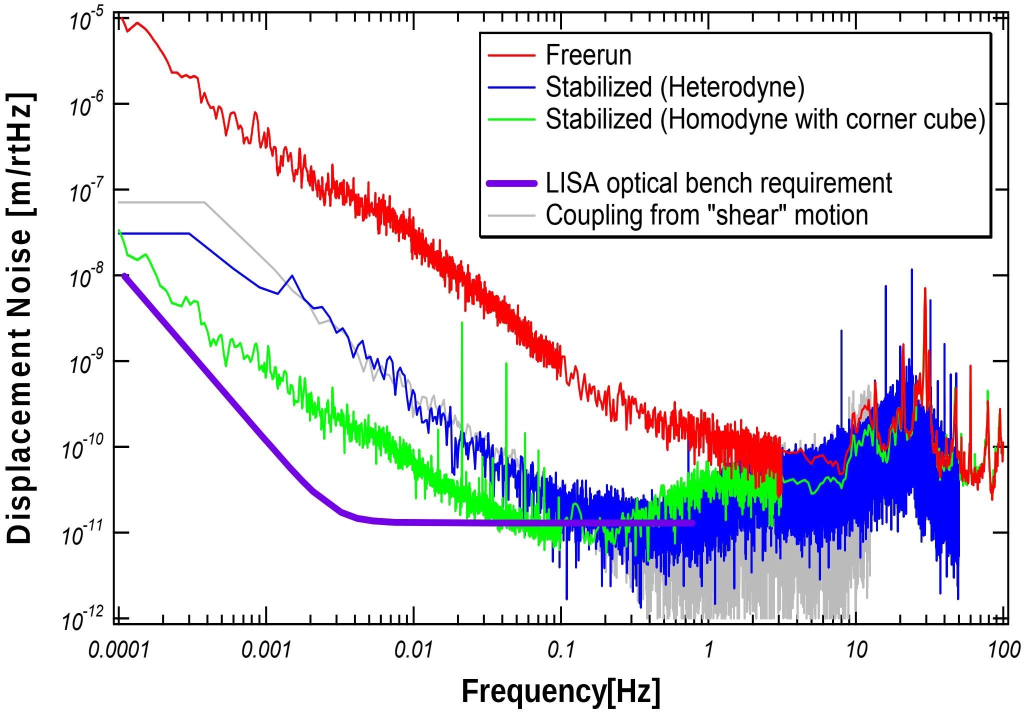
Outline

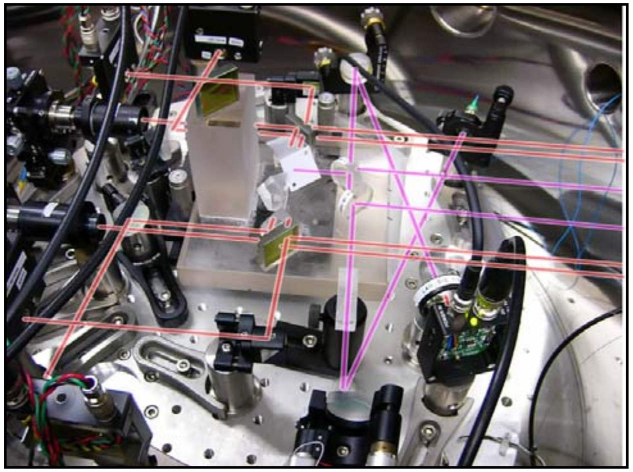
- Laser Frequency Stabilization
  - Optical Cavities with frequency tuning
  - Molecular Iodine
- Stable Environments
  - Stable test-bed for formation flying
  - Fused-silica fibers for torsion pendula
- Surface Effects
  - Kelvin Probe
- Laser Study

Interferometer Testbed

Numata & Camp

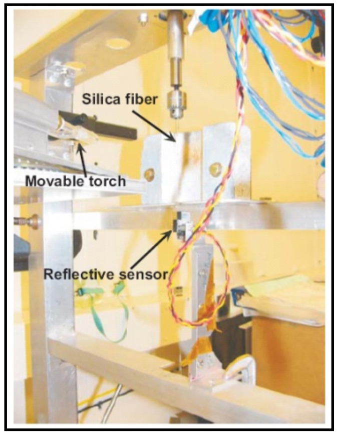
- Testing LISA's inter-spacecraft interferometer on stable platforms
  - 2 optical benches with 2 independent pre-stabilized lasers
    - Silicate bonded optical bench, heterodyne interferometer with phasemeter
  - 2 degree-of-freedom active control
    - Intended to kill unwanted ground & thermal motion.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



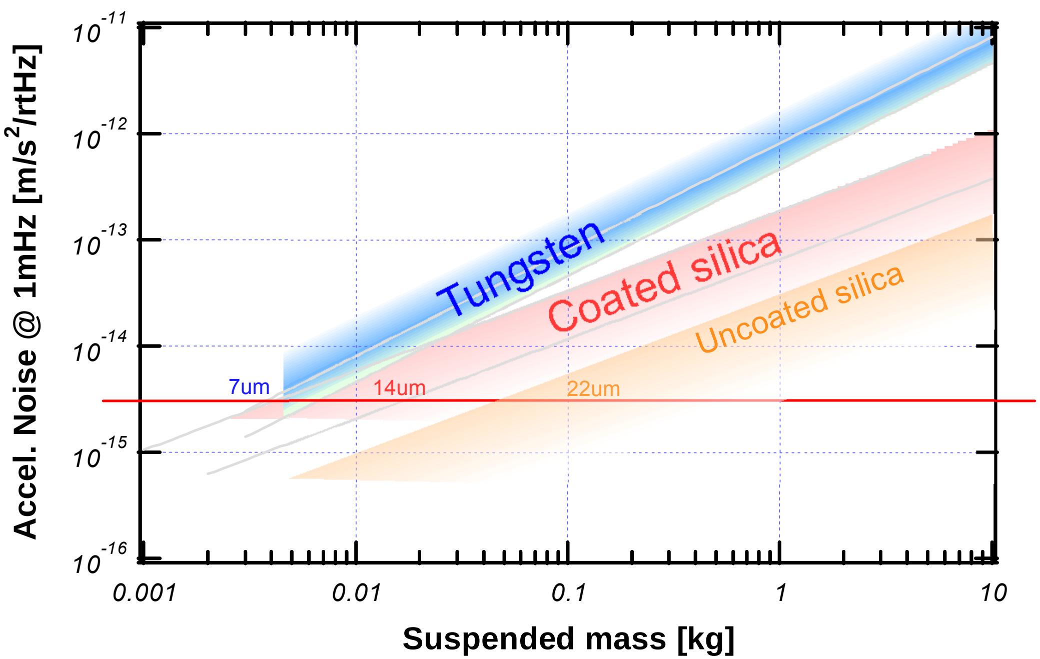


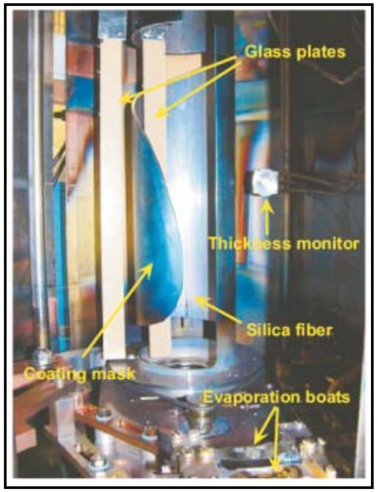
Silica Fiber for Force Noise Test

- 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



Fiber puller





Fiber coater

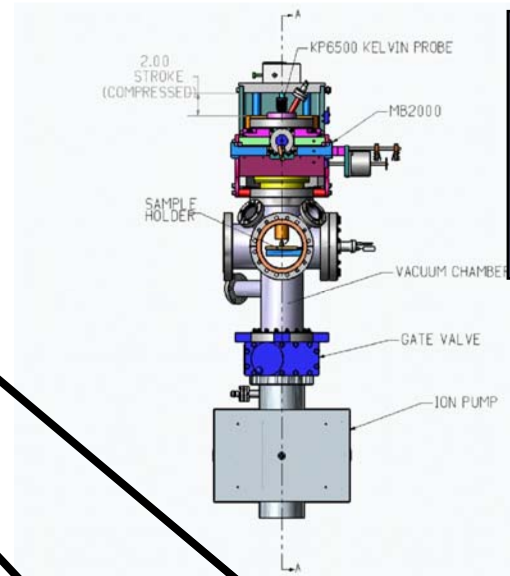
Numata & Camp

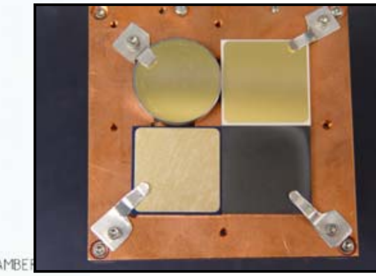
Outline

- 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

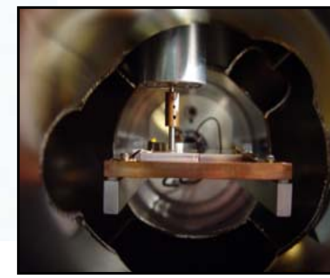
KP measurements of LISA gold surface

- 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

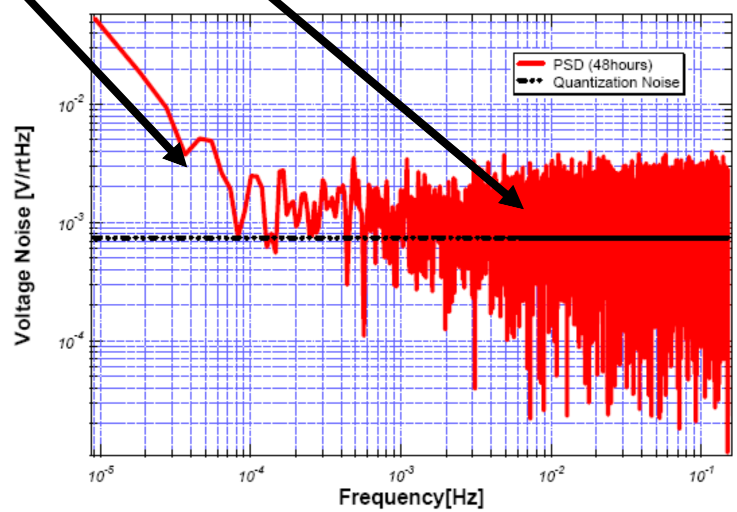




Coated Samples



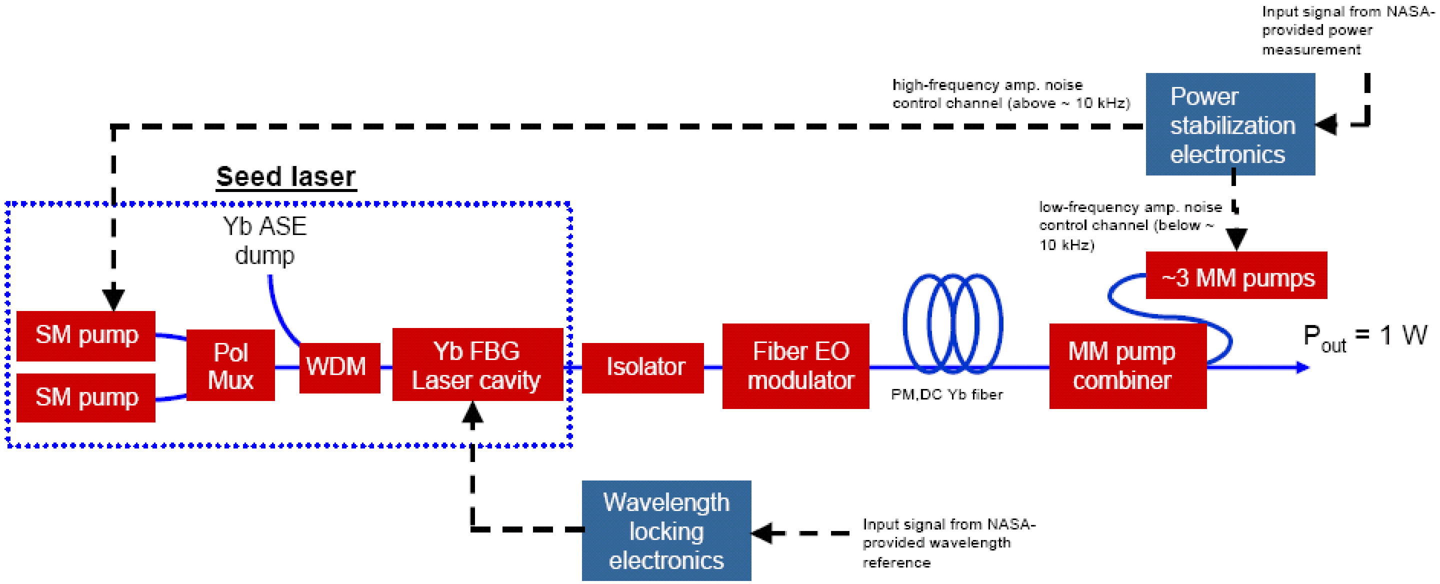
ST-7 sample under test



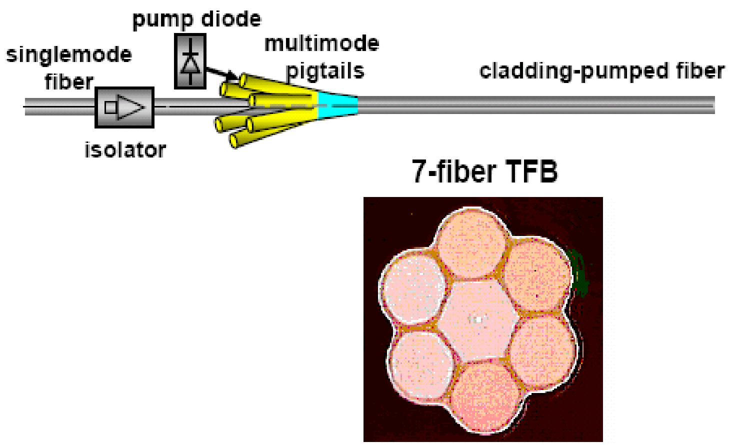
Camp

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

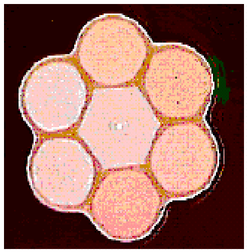


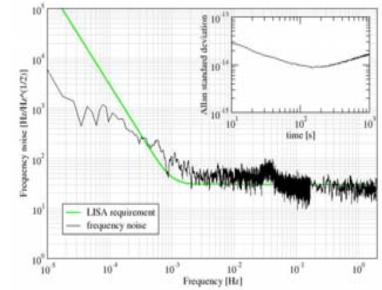
- Testing of pump combiner
  - optical characterization (insertion loss and PER stability) from 5 - 70 C
  - thermal screening under high power in vacuum
  - temperature cycling in air



J. Camp

Questions?





Contributors

Jordan Camp

Volker Leonhart

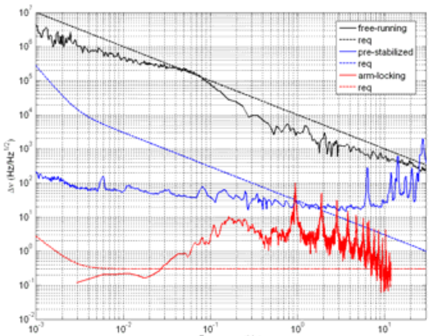
Jeff Livas

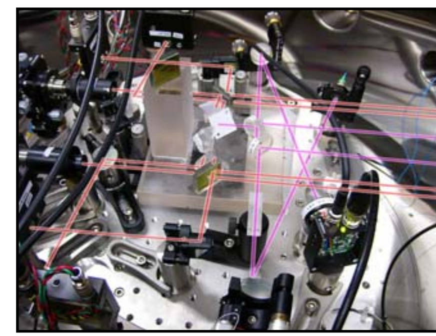
Shawn Mitryk (GSFC/UF)

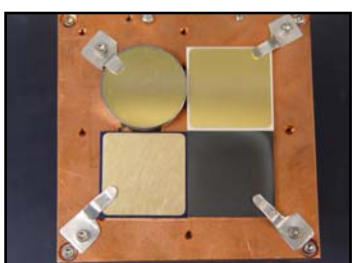
Kenji Numata

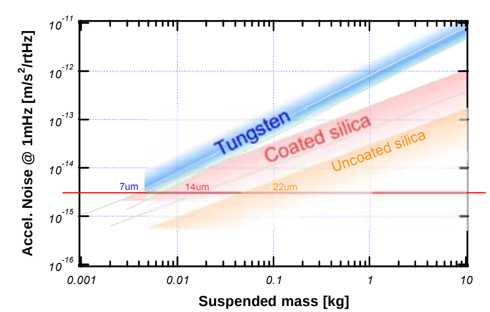
Ira Thorpe

Vinzenz Wand (UF)



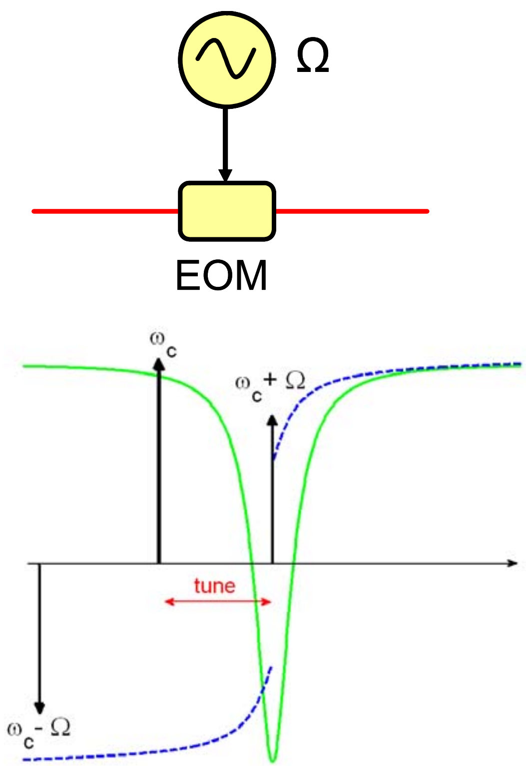






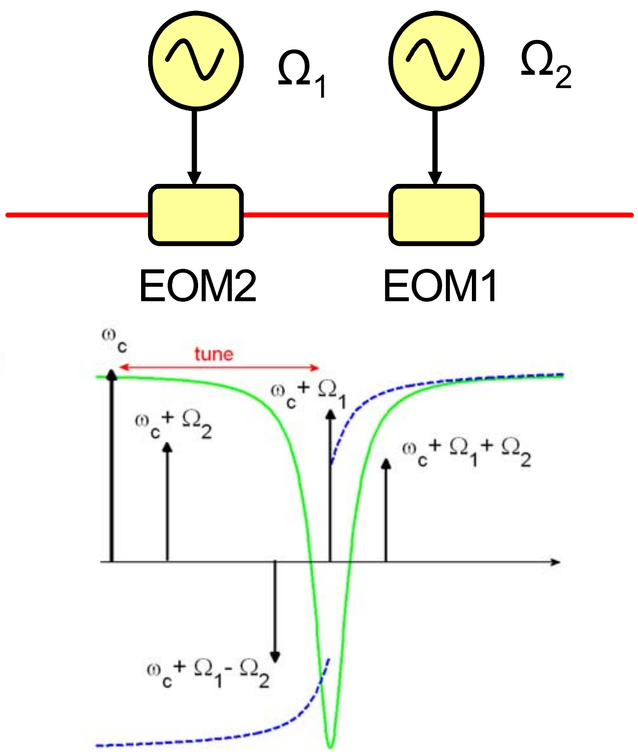
Backup Slides

Single Sideband (SSB)



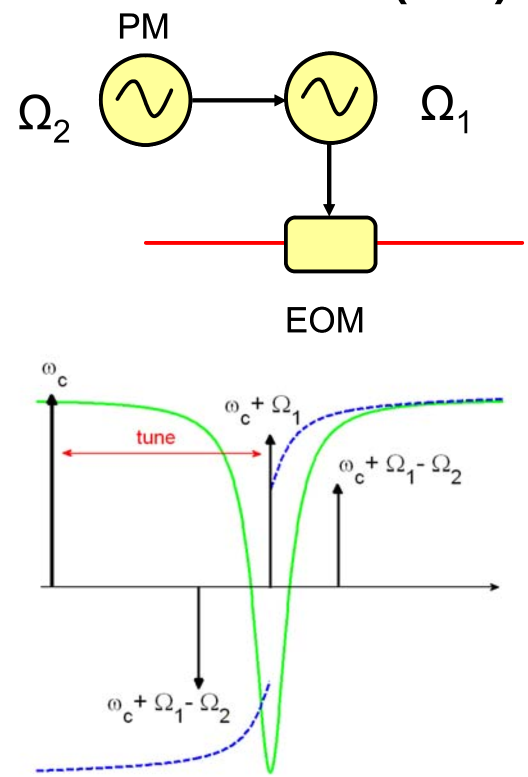
- Simplest to implement
- Some noise coupling due to asymmetry

Dual Sideband (DSB)



- Restores PDH symmetry
- Complex modulation pattern

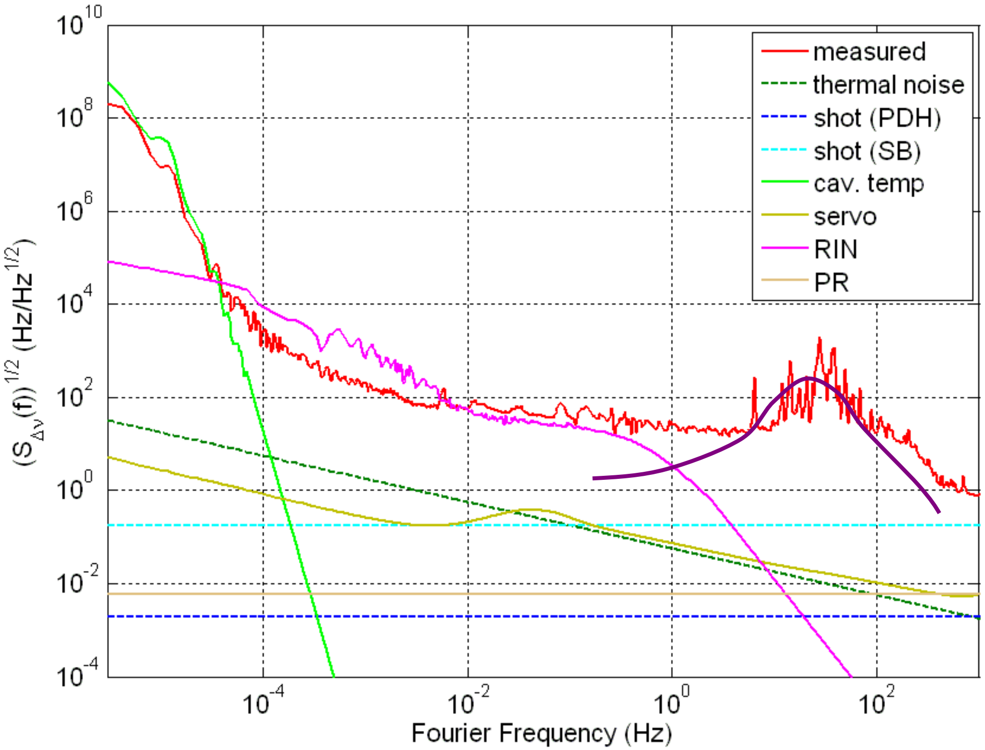
Electronic Sideband (ESB)



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

Preliminary Noise Model

- Fundamental Noise
  - Shot noise
  - Cavity thermal noise
- Technical Noise
  - Temperature Fluctuations
  - Servo Noise
  - Photoreceiver noise
  - RIN
    - via RFAM
    - via absorption
  - Vibration Noise/Acoustic
  - Pointing
  - ???



Arm-Locking Transfer Function

- Measured noise suppression matches expectations
- ~40dB at 100mHz