LISA Research and Development

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Aspen Winter GW Conference 2003

Contents of This Talk

- Brief Introduction to LISA
- Interferometry R&D
- Acceleration noise R&D
  - ST-7, LTP test flight

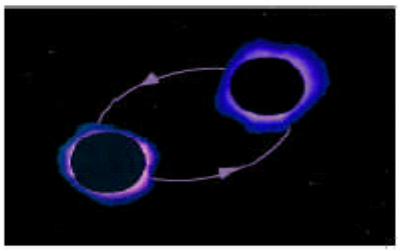
LISA News Flash!

- **Beyond Einstein Theme included in Presidents FY 04 Budget**
  - **LISA ranked first mission. Launch 2011**
    - **Pending successful TRIP review this spring**
    - **$30 M budget for FY04**
    - **Official Project start this summer**
  - **Con-X next. Launch 2014**

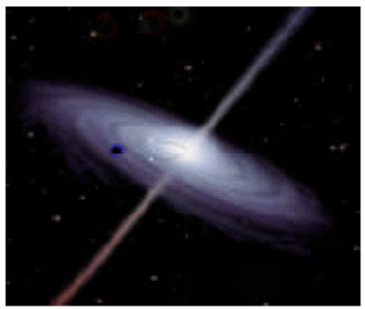
The LISA Mission

LISA Science Goals

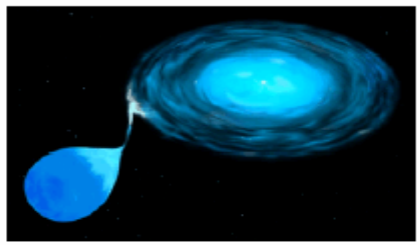
LISA will observe gravitational waves from:



Massive Black Holes; forming from coalescence of seed black holes or from collapse of dense gas clouds, super-massive stars or relativistic star clusters; or coalescing from galaxy mergers



Stellar-mass black holes orbiting massive black holes

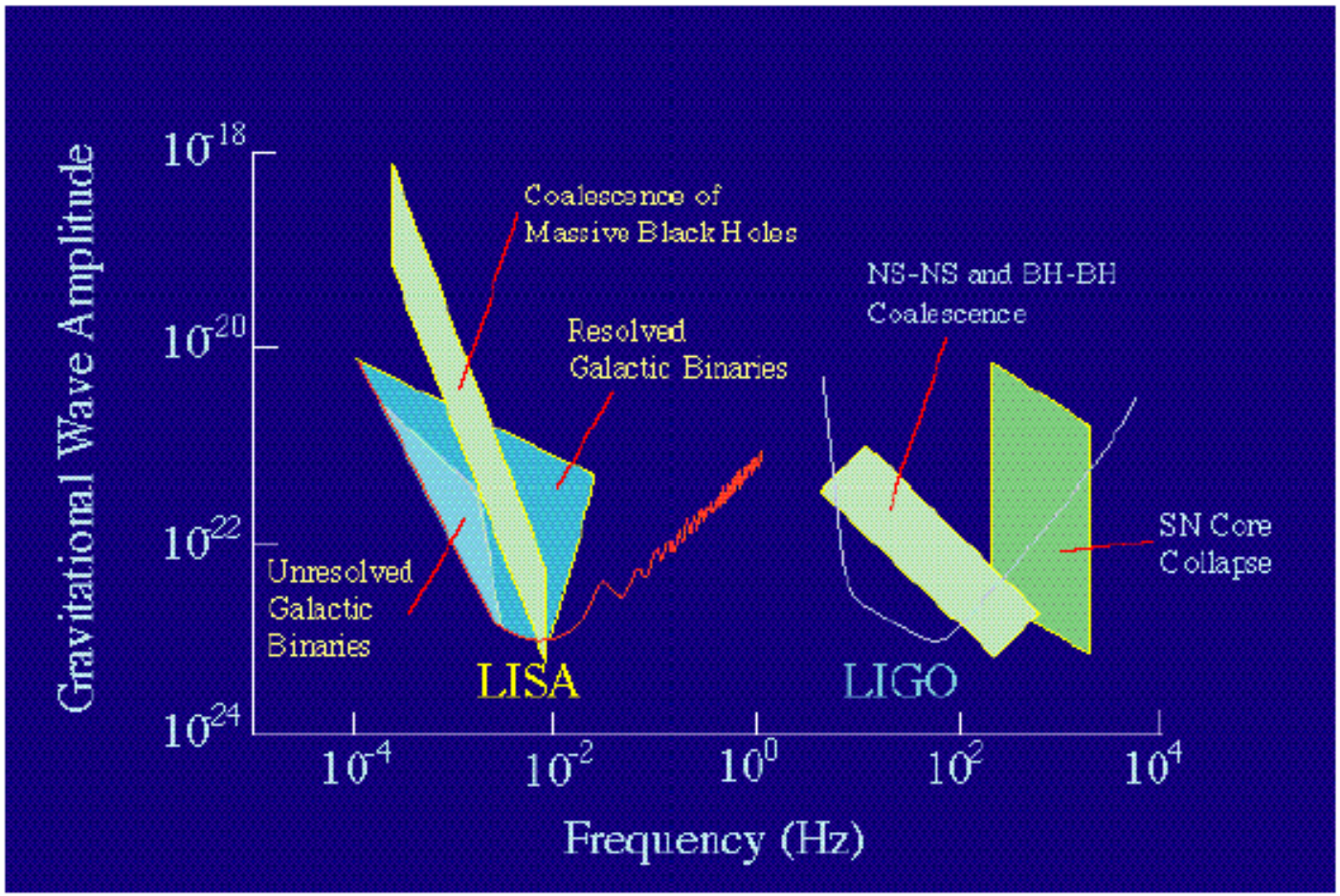


Compact binary star systems

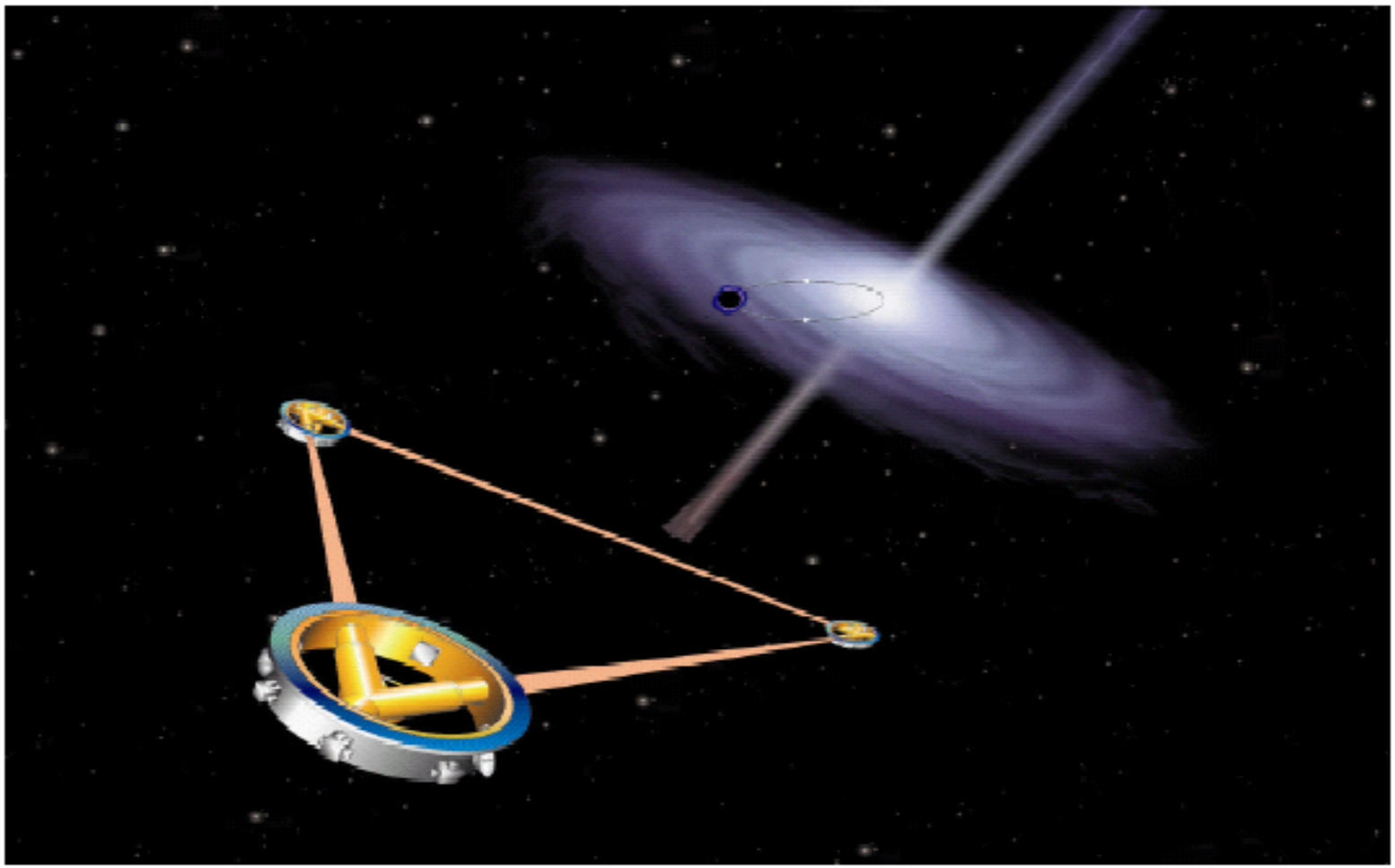
LISA 3

LISA

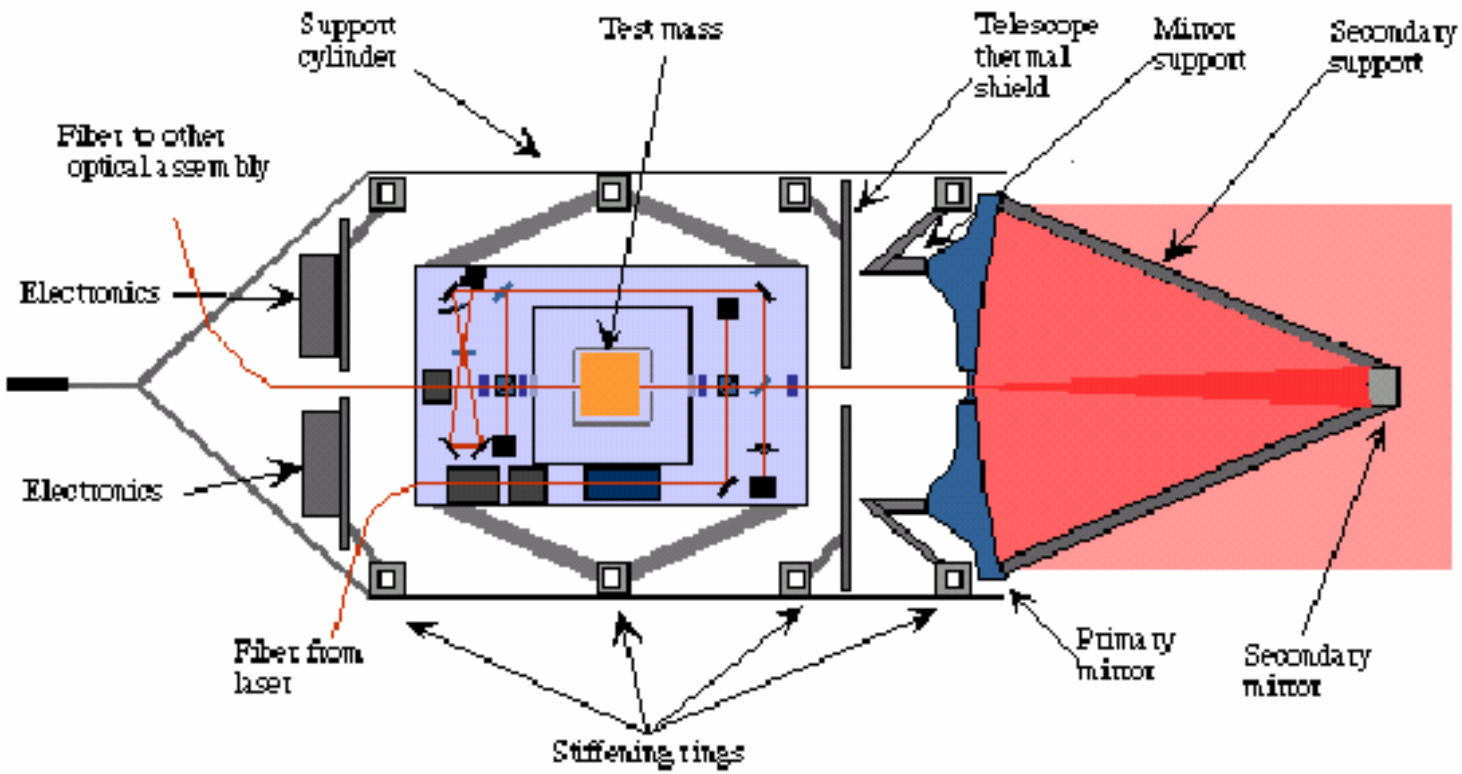
Anticipated LISA Signals



Mission Concept: Space Michelson Interferometer



Optical Layout



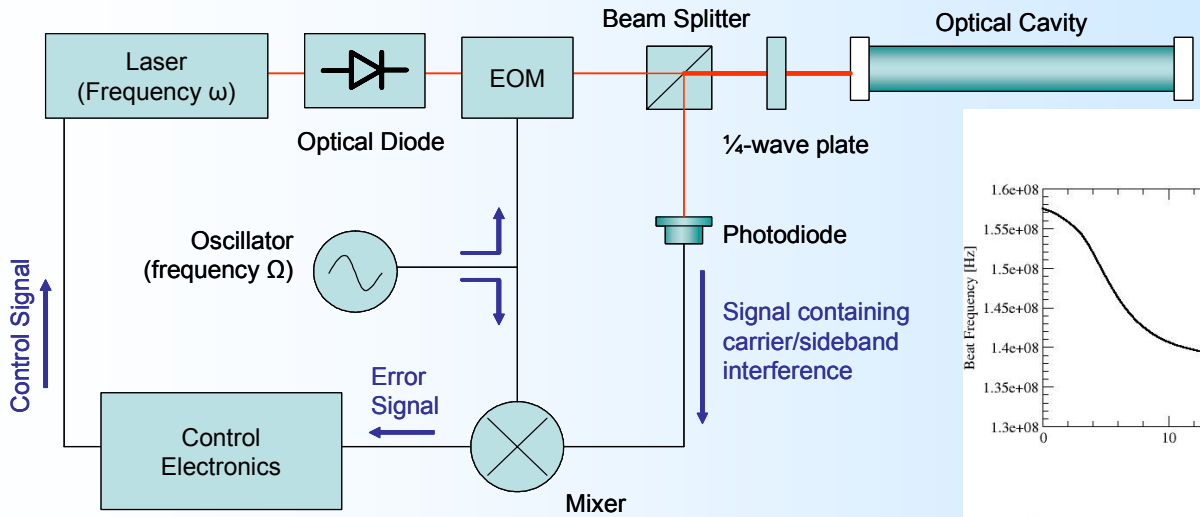
LISA Research and Development

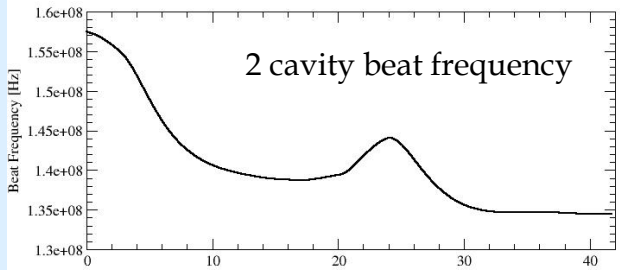
- Interferometry
  - (space) measurement of 10^{-12} m over 1000 sec
    - many associated technical issues
- Acceleration noise on test mass
  - 3×10^{-15} m/sec^2/sqrt(Hz) over 1000 sec
    - to be validated by ST-7, LTP
- Ground testing of above before launch

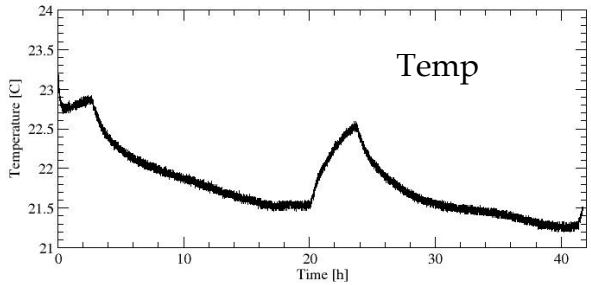
Technology of space interferometry

- Technology of picometer interferometry *in space*
  - laser stabilization: demonstrate frequency stability of 1 part in 10^{14} over 1000 sec timescale
  - materials stability: measure material length stability after launch stress at picometer level
  - signal readout: phase readout of LISA mHz signals in presence of space-induced Doppler shift
  - time delay interferometry: attenuation of frequency noise to $1{:}10^{6}$ by time-shifting Michelson arm signals

Laser Frequency Stabilization I
Optical Cavity





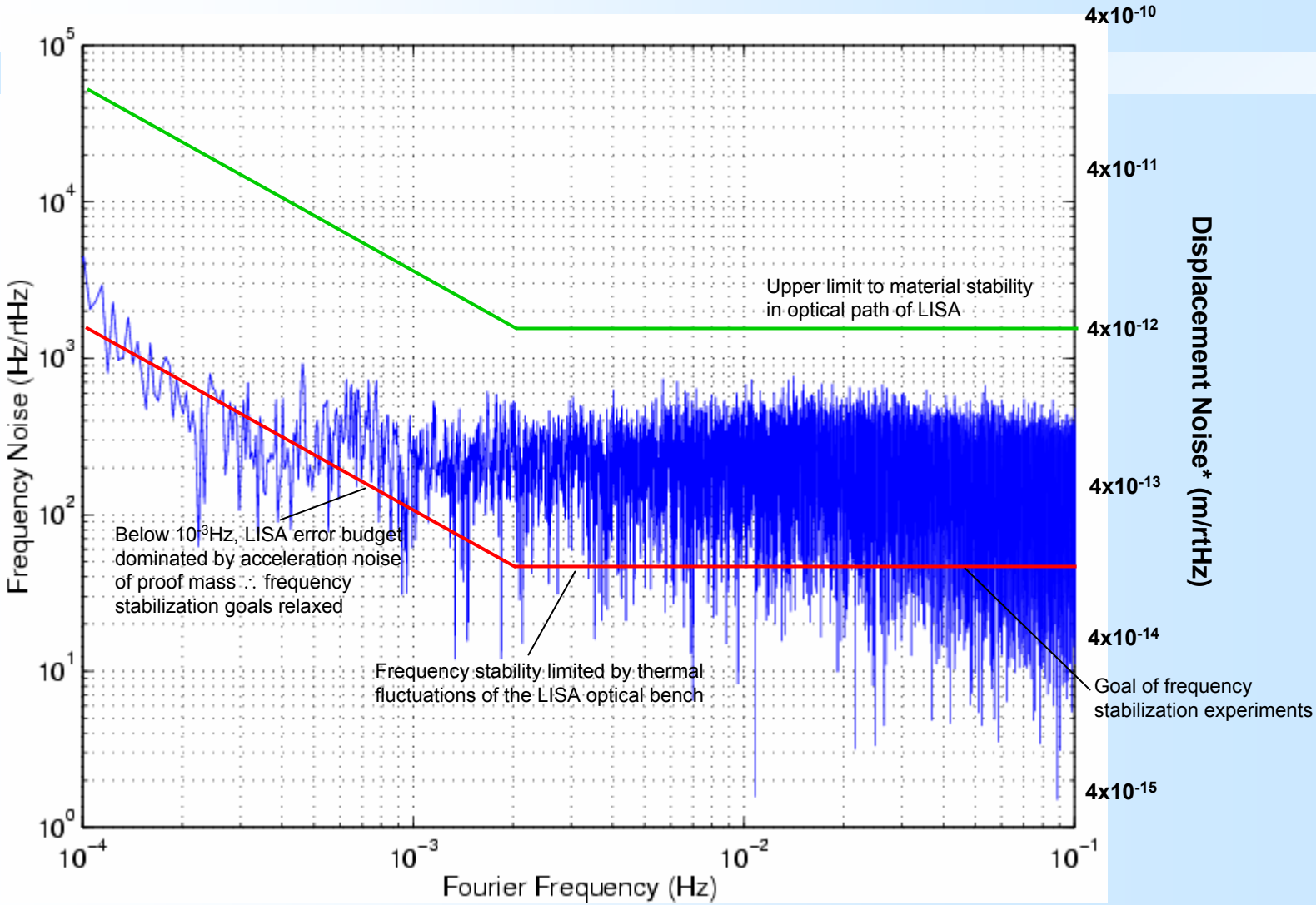


- Frequency variation dominated by temperature
  - 1 degree C is ~ 1 nm change for ULE cavity
  - next: temperature stabilization of cavity

Temperature Stabilization of Cavity

- **Gold coated cylinders limit radiative transfer to cavity**

Power Spectrum of Beat Note
(Muller, McNamara)

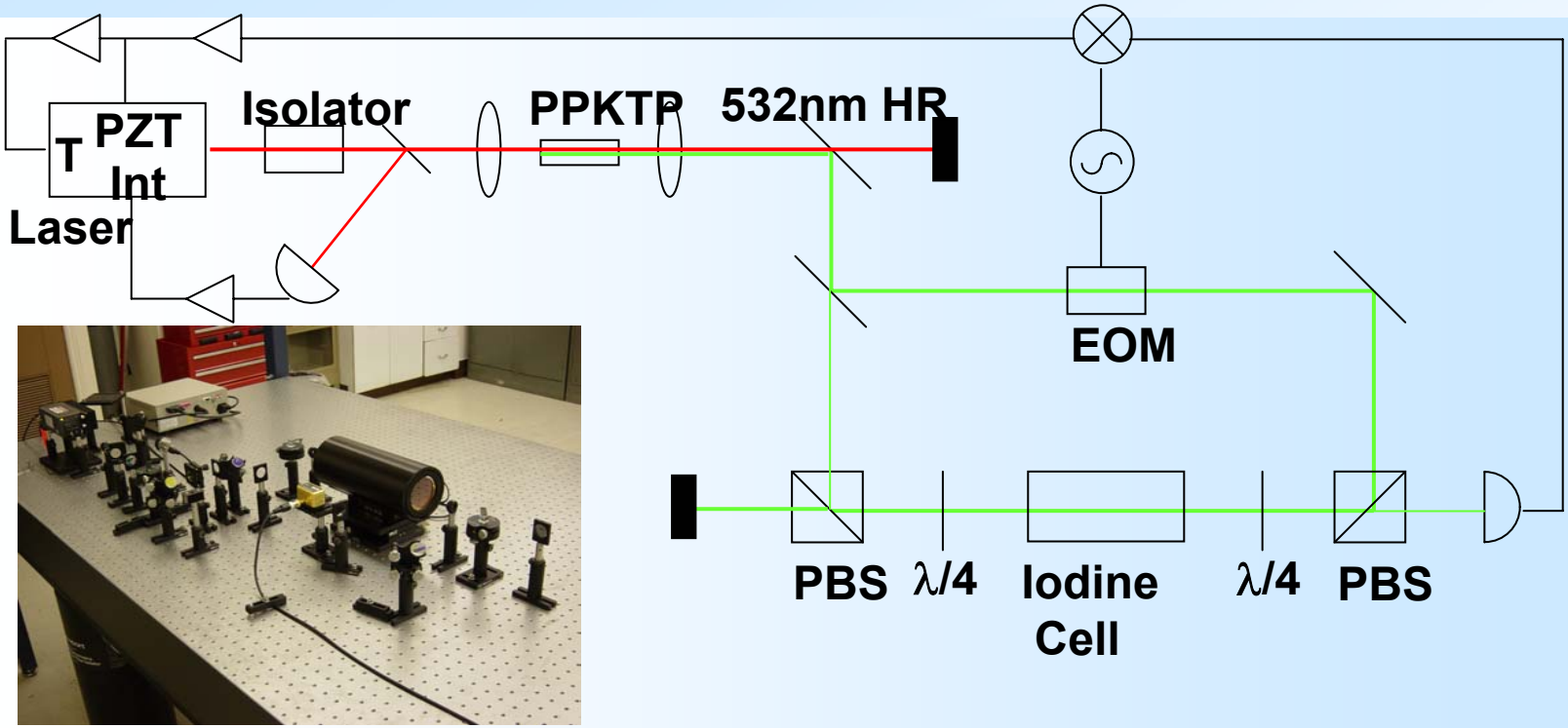


Laser Frequency Stabilization II: Iodine

- Iodine stabilization of NPRO laser
  - use of iodine atomic transition as frequency reference
    - highly stable (cavity/100 at 10^{-4} Hz)
    - fixed frequency, temperature insensitive
    - optical setup more complicated than cavity

- Iodine R&D
    - provides frequency reference for LISA R&D
    - interferometric sensing of LISA and other formation flying missions
      - can we *space-qualify* iodine setup?

Iodine Stabilization Optical Layout



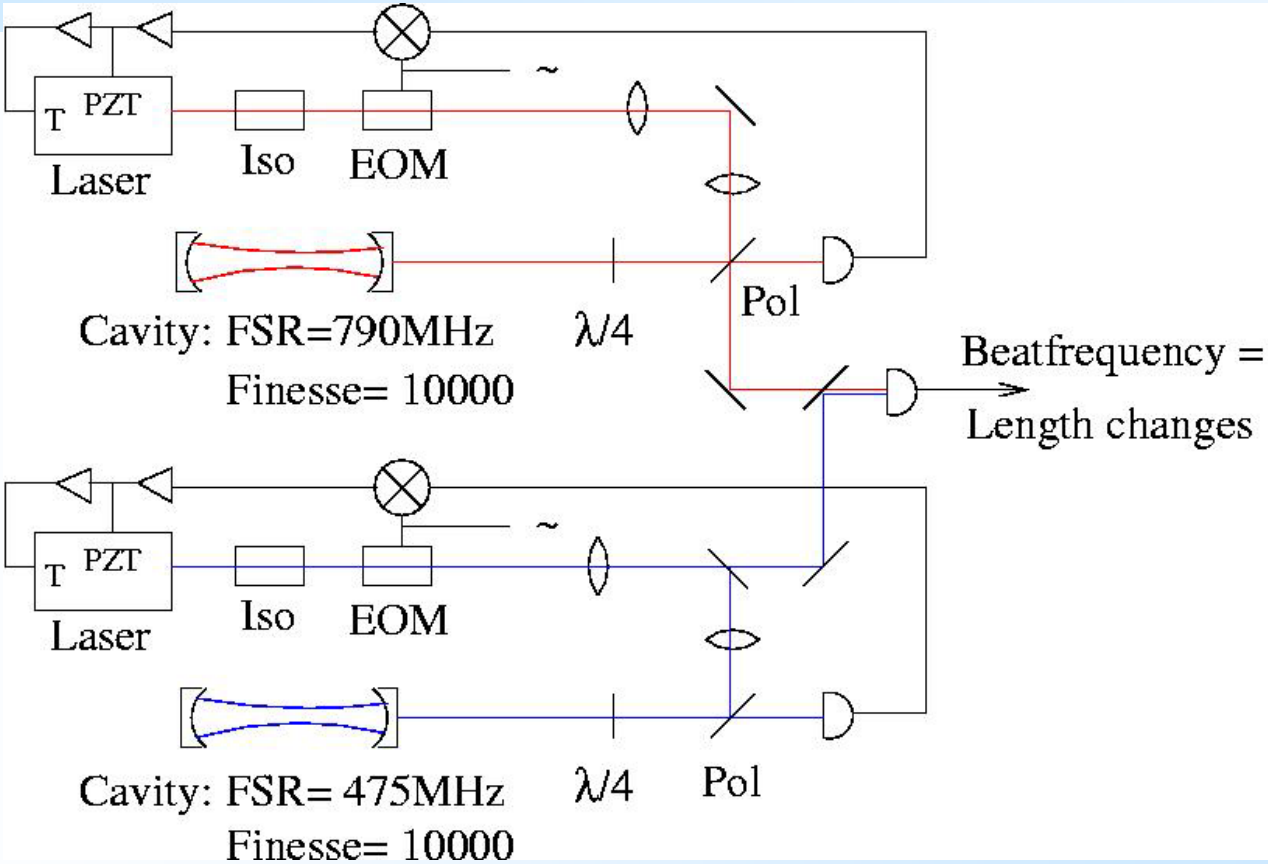
- Iodine stabilized lasers are an option for use in LISA
- Iodine stabilized laser will be used to monitor stability of cavity-stabilized lasers
- First results from iodine stabilization expected 1st Qtr 2003

Material Stability Studies

- LISA requires highly stable optical pathlength
  - variety of materials between detectors
    - ULE
    - carbon epoxy
    - optical bonds
  - materials subject to launch stress and vibration
    - stability unknown at picometer level

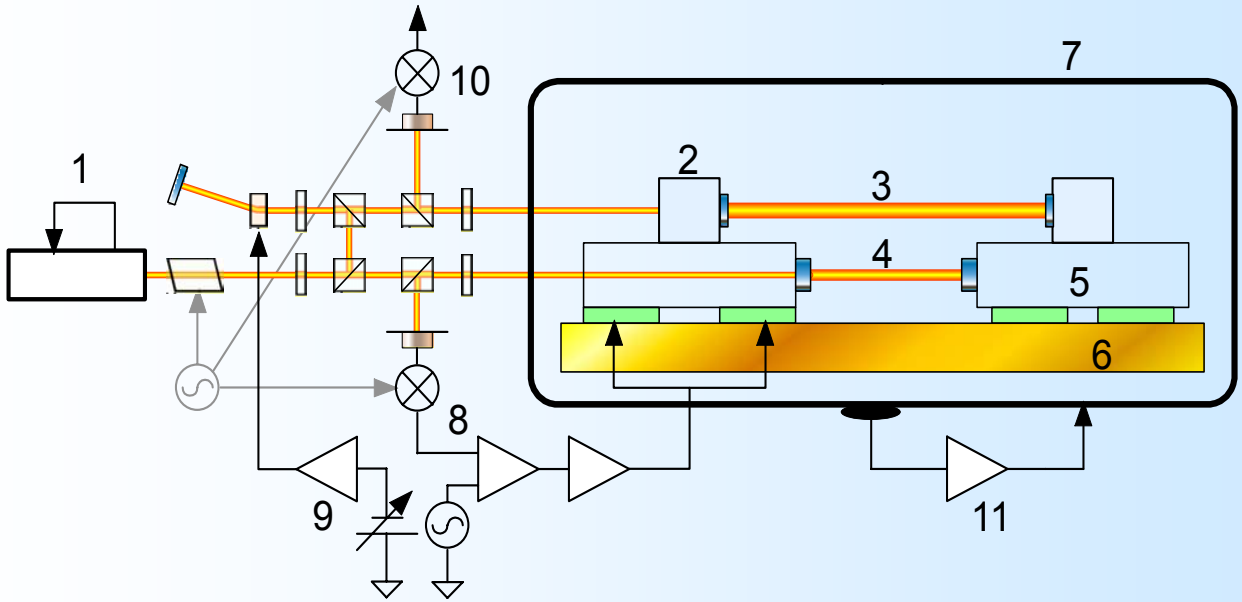
- research program initiated to study material stability
  - use stabilized laser to track length of stressed material
    - temperature stabilized optical cavity
    - iodine cell

"Material Investigation" Optical Layout



- Each laser locked to own cavity (currently, both cavities made of ULE)
- Light from lasers beat together on photodiode
- Beat note recorded and power spectrum calculated

Ground Testing: Control Systems for Ground Interferometry



- Development of control systems to remove thermal and seismic noise
  - auxiliary systems monitor and attenuate noise and provide calibration
  - interferometry can then be tested in quiet environment (I&T)

Acceleration Noise R&D

- Acceleration noise < 3 x 10^{-15} m/sec^2/sqrt(Hz) at 1 mHz

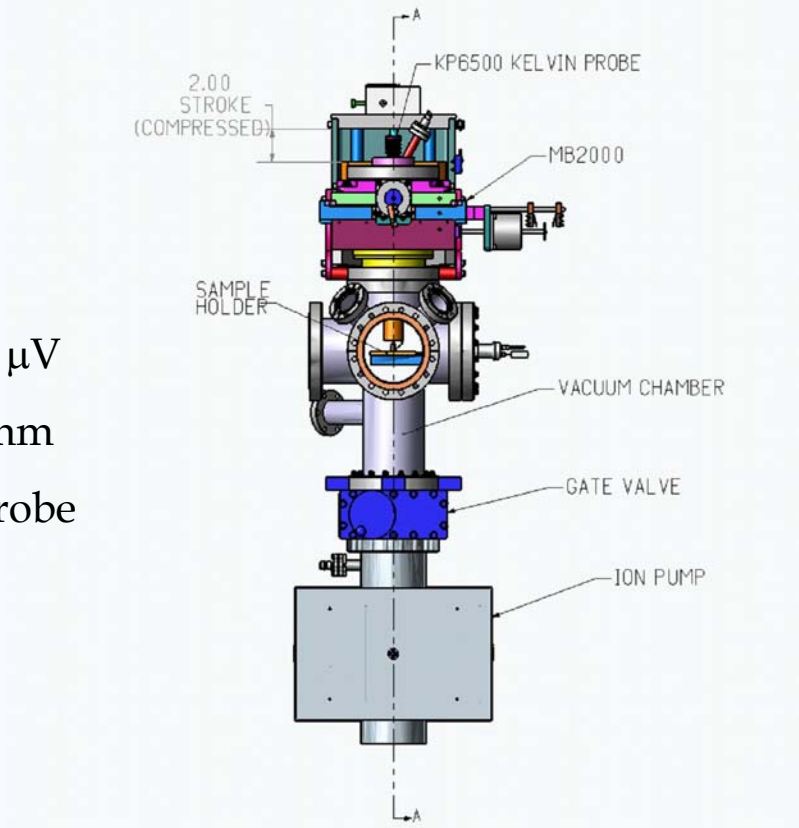
- Sources of acceleration noise

Type of noise	Magnitude	Coupling	Mitigation
Residual gas	0.2	10^{-7} torr	Vacuum pump
Radiation pressure	0.3	$\delta T \sim 50\ \mu K$	Thermal design
Charge fluctuation	0.1	10 e^- / sec	Discharging
Voltage fluctuation	0.2	$\delta V \sim 10\ \mu V$	Gold coating
Gravity gradient	0.01	$\delta x \sim 10^{-8}$ m	Drag-free control
Grav sensor stiffness	0.4	$\delta x \sim 10^{-8}$ m	Drag-free control

- ST-7, LTP will test understanding of these noise terms

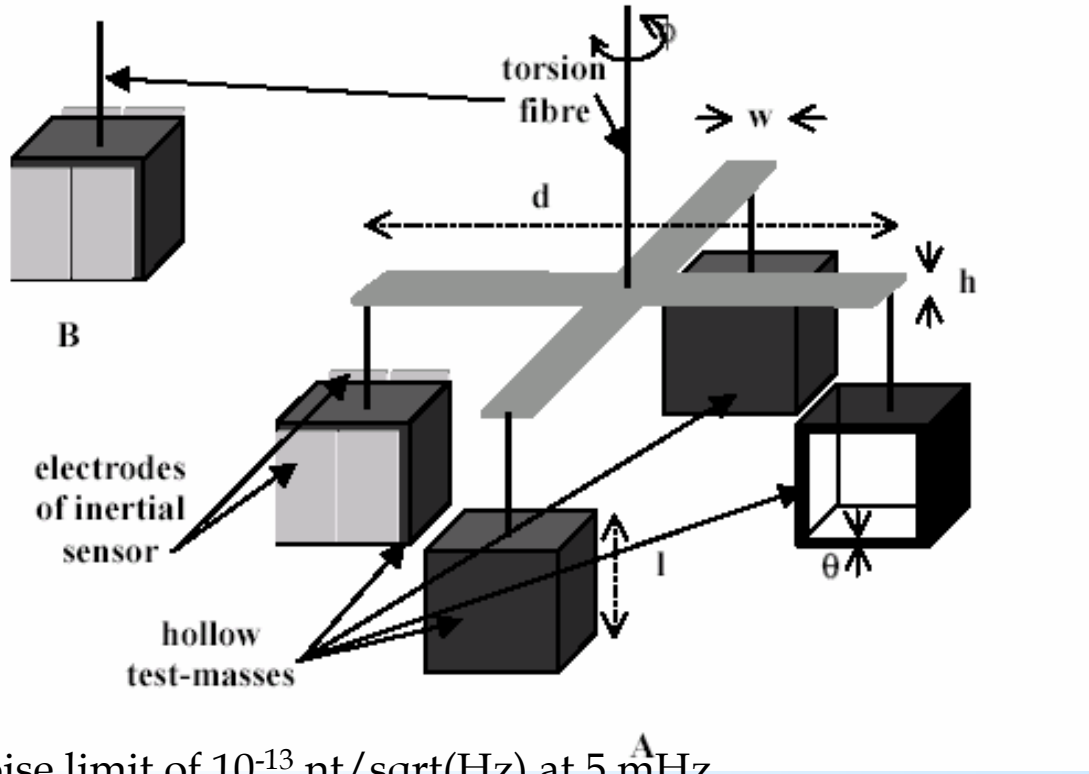
Mother of all Kelvin Probes: Study of Surface Voltage Noise

- Voltage sensitivity 100 µV
- Spatial sensitivity 0.4 mm
- Gold coated sample, probe



- Delivery of Probe in March

Acceleration Noise Measurements: Torsion Pendulum



- Thermal noise limit of 10^{-13} nt/sqrt(Hz) at 5 mHz
  - Grav sensor stiffness: S. Vitale (U. Trento)
  - Surface voltage variation: J. Gundlach (U. Washington)
- possible improvement of sensitivity with fused silica fiber

LISA Project Schedule

- Technology Development 2003 - 2006
- SM2 flight in 2006
  - NASA and ESA test packages
  - validation of noise models
  - downselection of project technologies
- Design and Fabrication 2006 - 2010
- Integration and Test 2010 - 2011
- Launch 2011