GW Interferometry at Goddard Space Flight Center

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NASA / Goddard Space Flight Center

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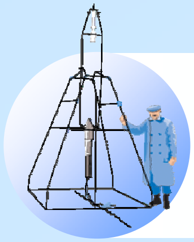
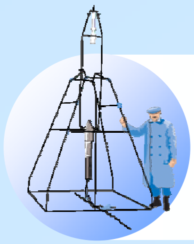


This Talk

- Frequency stabilization of lasers
  - Optical cavity
  - Molecular iodine
- Suspension point interferometer (SPI) for testing of low-frequency interferometry
- A few “politically correct” slides
  - New science direction for NASA



Interferometry in Space

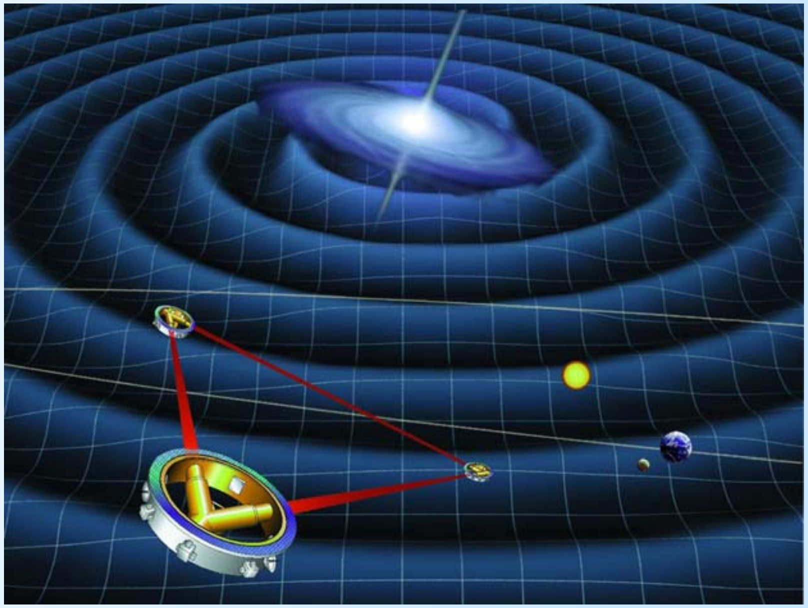
- Space interferometry a strategic direction in astronomy
- NASA and ESA are planning a significant number of space interferometry missions

– SIM	2010	Stellar interferometry
– LISA	2014	Gravitational Waves
– TPF-C	2015	
TPF	2020	Extra-solar terrestrial planets
Darwin	2020	
– MAXIM	2025	Black Hole imager (x-rays)
– Etc…		

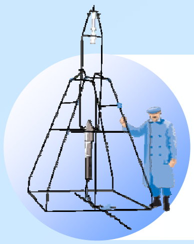
- Need frequency stabilized lasers for all of these…

LISA – Search for Gravitational Waves

- A variety of astrophysical phenomena produce low-frequency gravitational waves
  - Massive BH binary coalescence
  - Massive BH capture of stellar mass BH
  - Galactic compact binaries



- LISA will measure strain from GW's of 10^{-21}
  - Measure position to 10^{-12} m, spacecraft separation of 5×10^{9} m
  - $\Delta\nu / \nu \sim 10^{-21}$ for stabilized laser



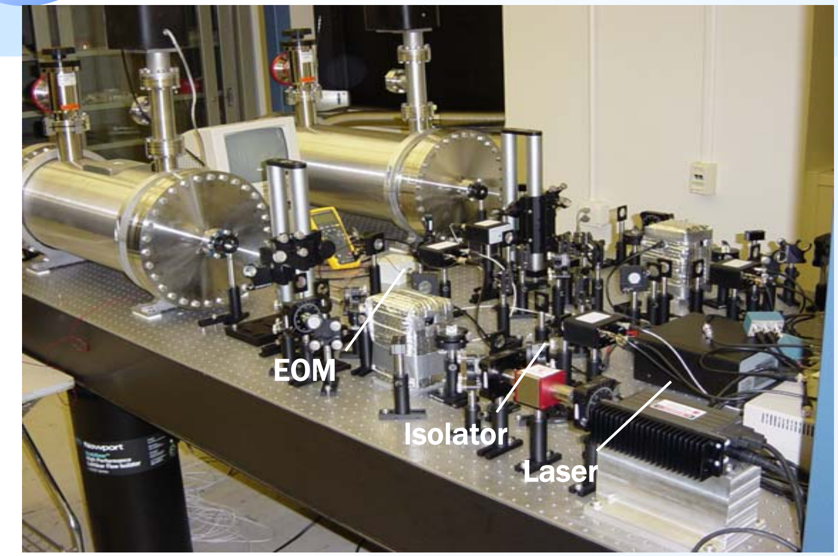
Methods of Laser Stabilization

- Frequency stabilization is only as good as the <u>stability of the reference</u>

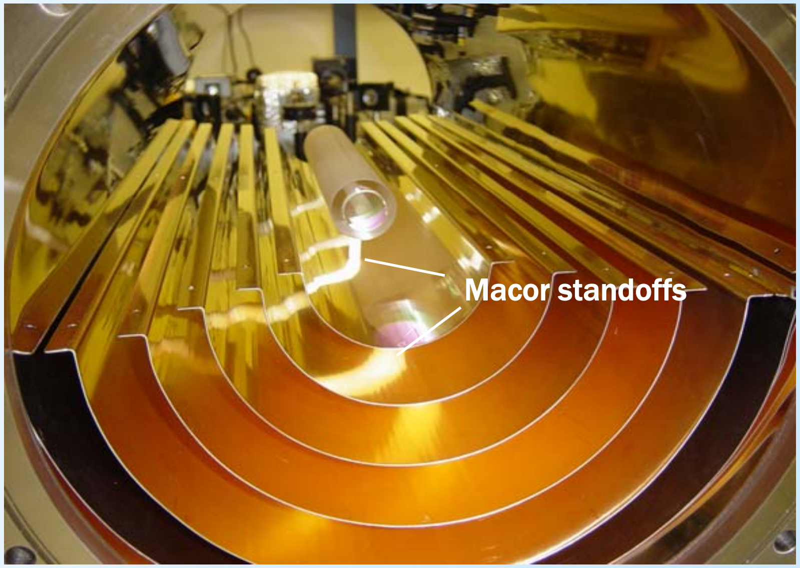
- Optical resonator
  - Low-loss mirrors held fixed by ULE cavity
  - Length of cavity determines resonant frequency
  - Variable DC frequency, temperature sensitive

- Atomic or molecular gas transition
  - Gas held in transparent cell
  - Transition provides absolute frequency reference
  - Better at low frequencies, worse at high (~ 1 mHz crossover)

Optical Cavities: experimental set-up

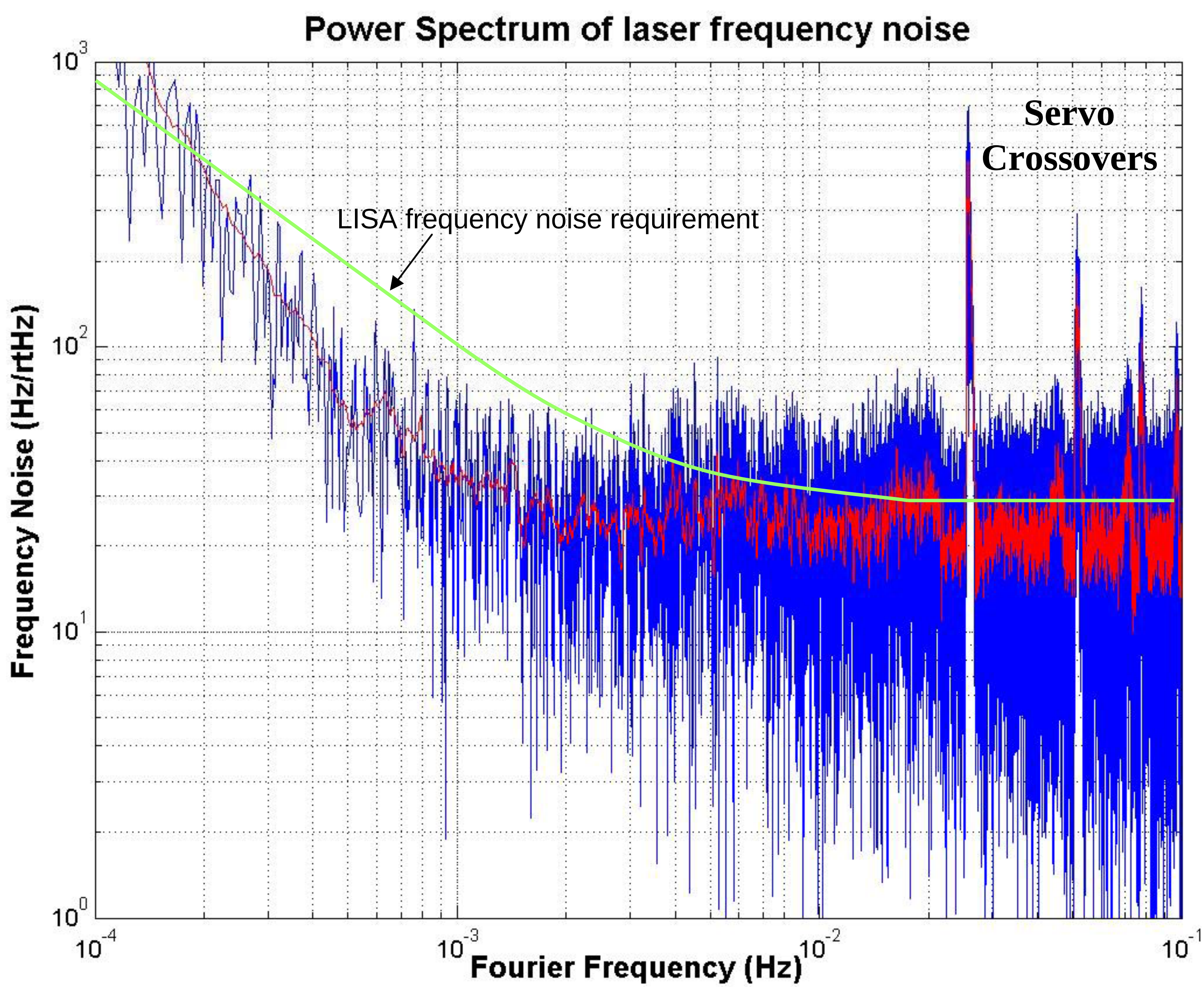


Cavities manufactured from ULE cylinders with fused silica mirrors optically contacted to end faces



Cavities in 5 layers of gold coated stainless steel in vacuum chamber

Results (Mueller, McNamara)

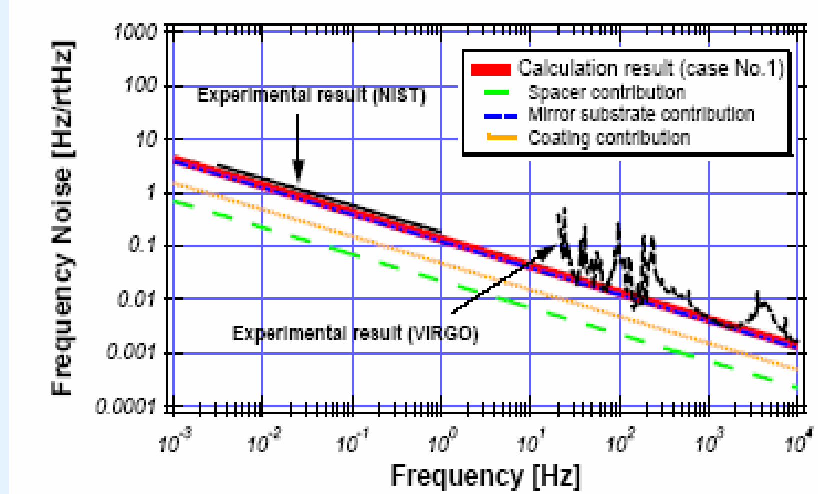


Thermal noise limit to cavity frequency stabilization (K. Numata)

- Thermal noise is fundamental limit to cavity stability
- Mechanical loss of spacer, mirror, coatings causes thermal noise

Limit ~ 3 Hz / Hz$^{1/2}$ 1 mHz

10^{-2} Hz / Hz$^{1/2}$ 100 Hz



NIST and VIRGO data both limited by ULE mirror substrates (Q ~ 6 x 10^4)

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Thermal-Noise Limit in the Frequency Stabilization of Lasers with Rigid Cavities

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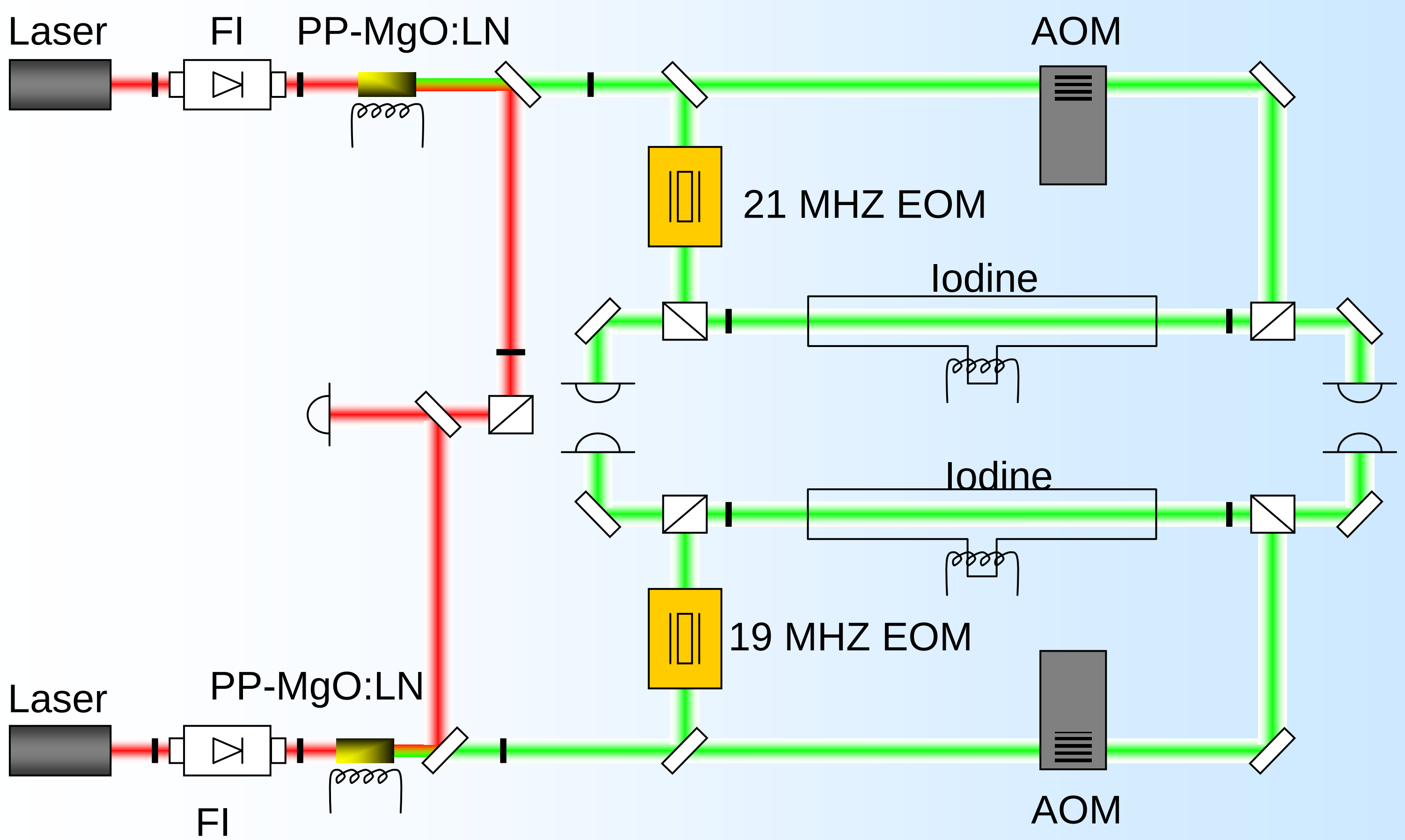
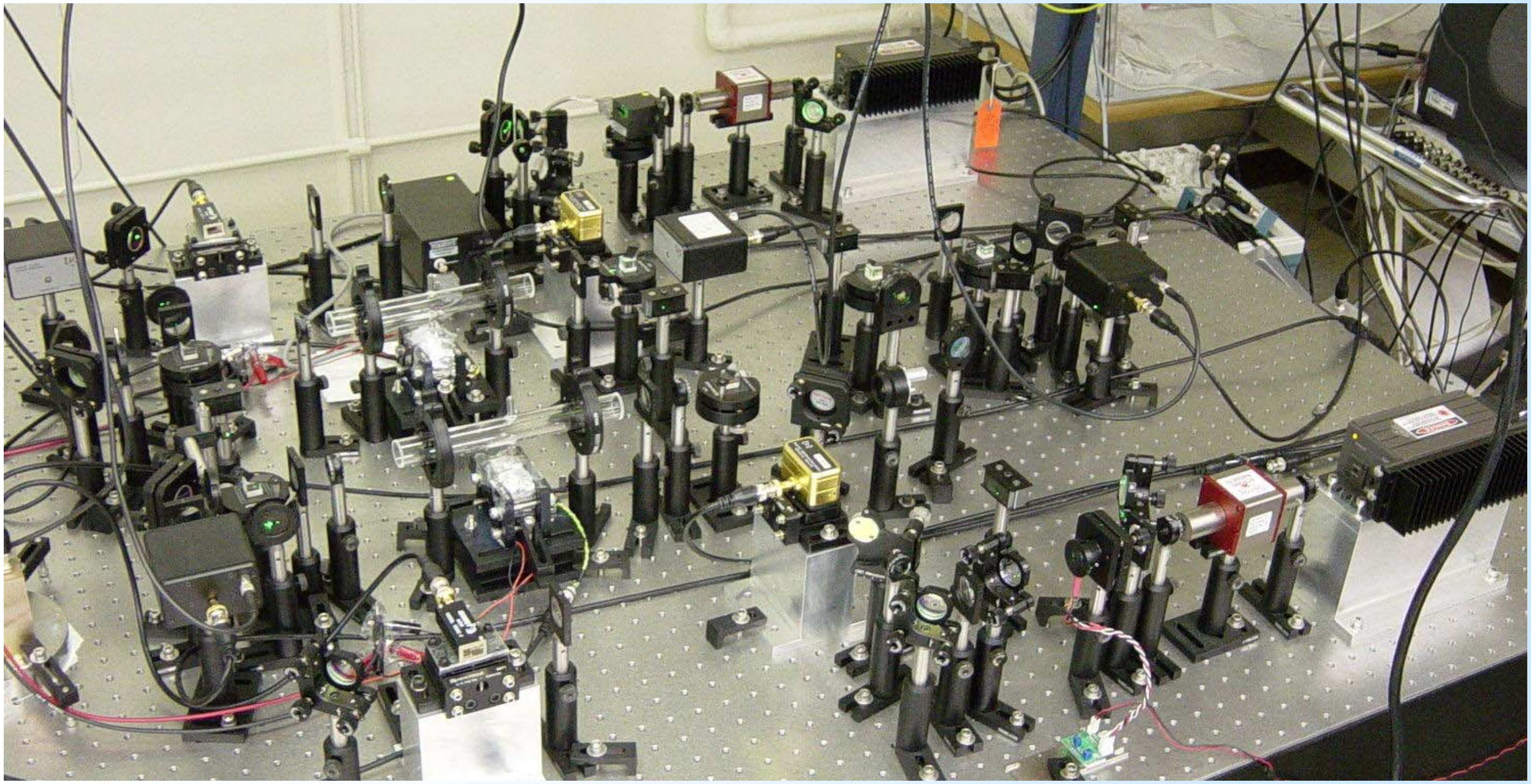
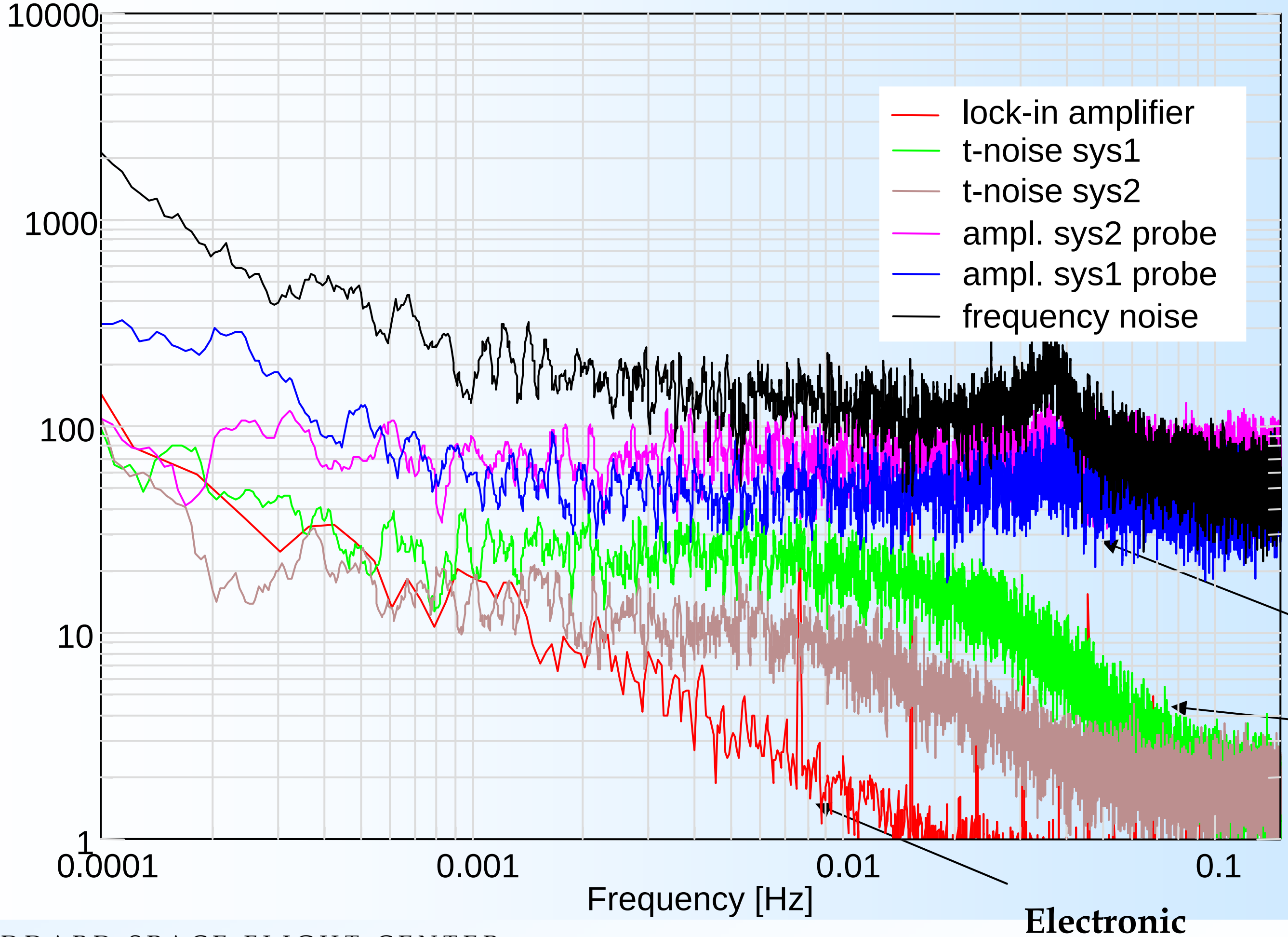
Iodine laser stabilization layout



Iodine stabilization laboratory setup



Iodine noise performance
(20 cm length cell) V. Leonhardt



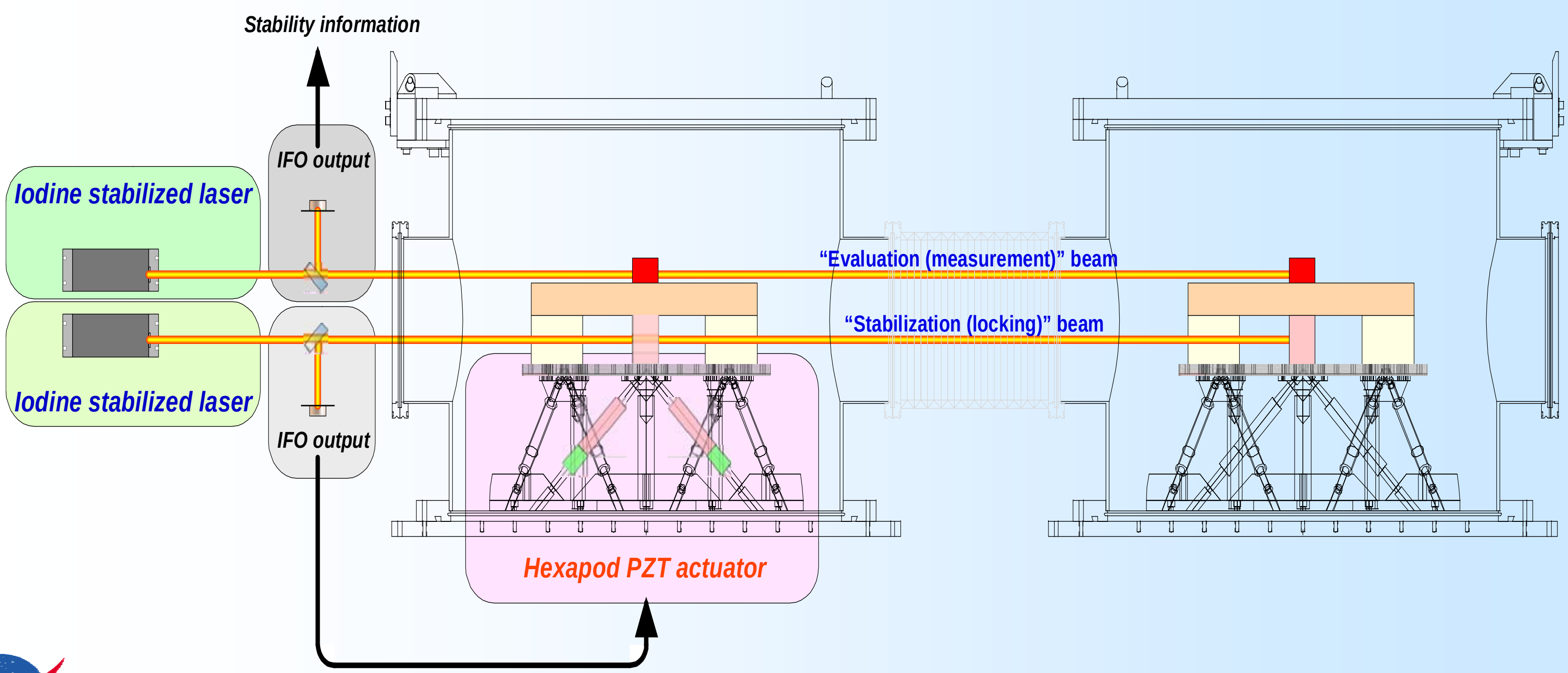
Absolute frequency

Insensitive to alignment and temperature

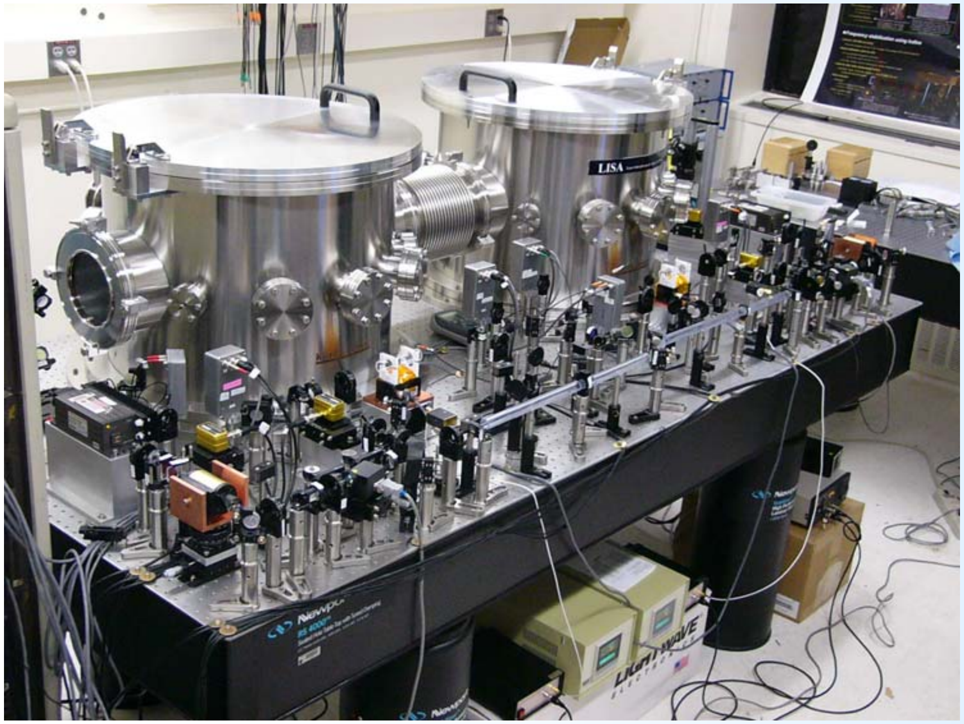
Low-Frequency Interferometry Testbed

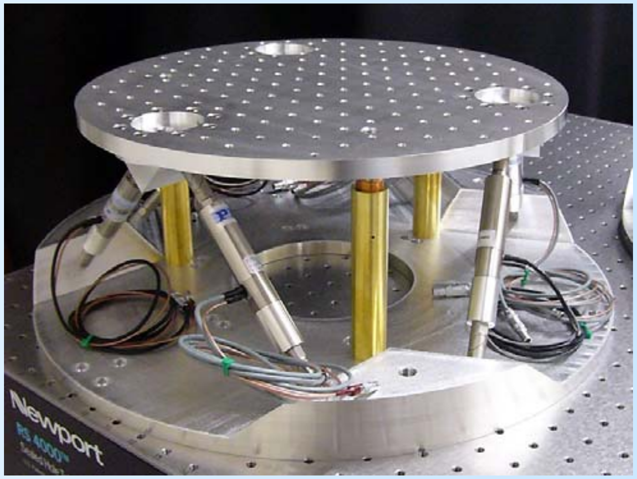
Suspension Point Interferometer testing platform

- goal: lock platforms at picometer, nanoradian level
- stable platforms will allow study of interferometry, noise



Suspension Point Interferometer

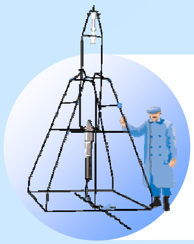




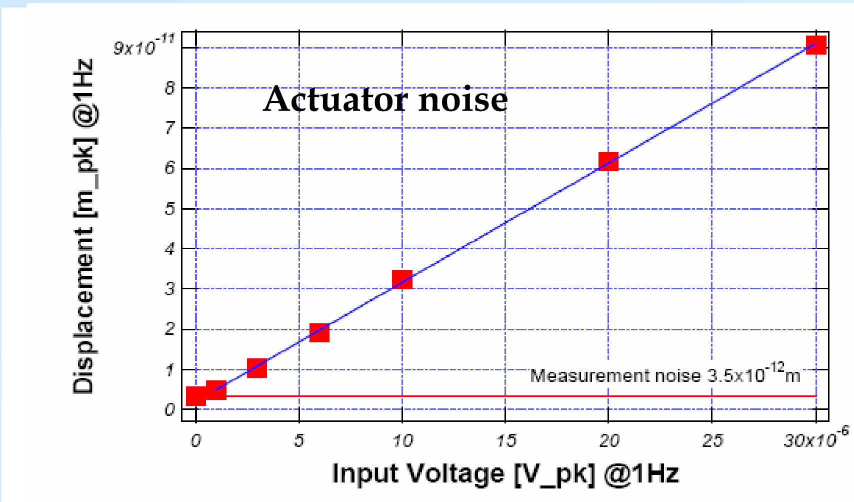
Hexapod: 6 PZT's for 6 DOF control

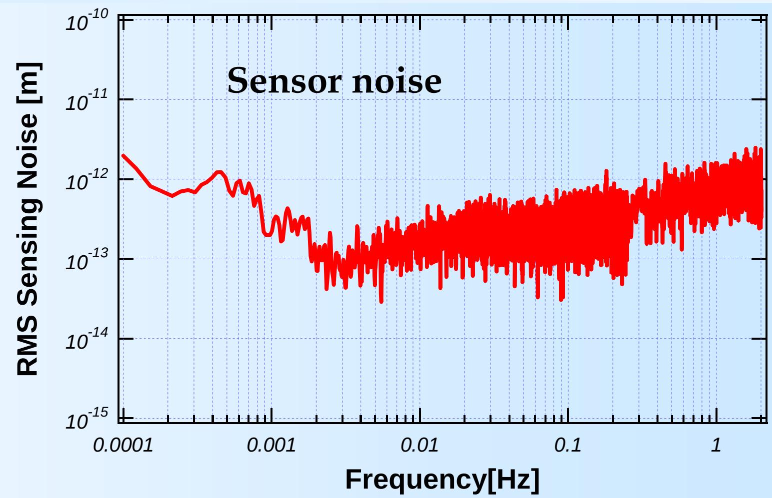
ν_{res} ~ 230 Hz, Q ~ 6

2 iodine stabilized lasers: sense/control hexapod, and measure residual noise

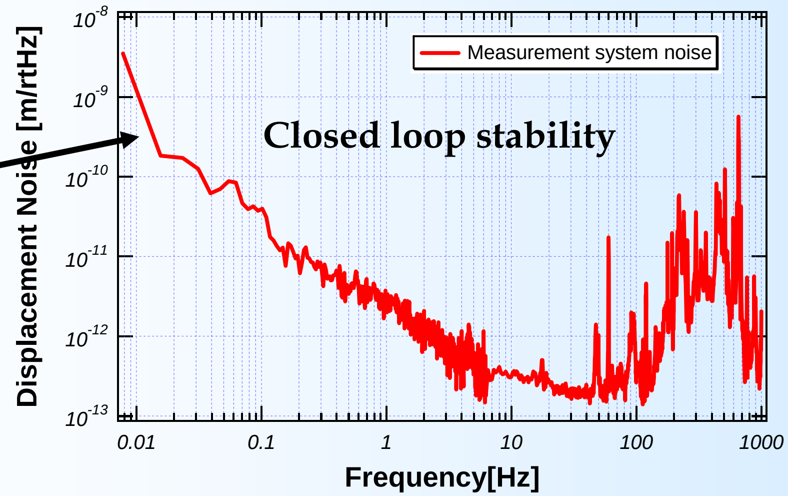


SPI Performance so far

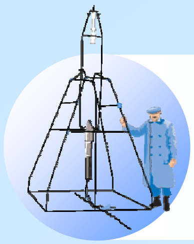




Stability limited by CTE of mechanical mounts

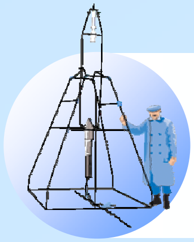


<u>Next:</u> use ULE and bonded optics



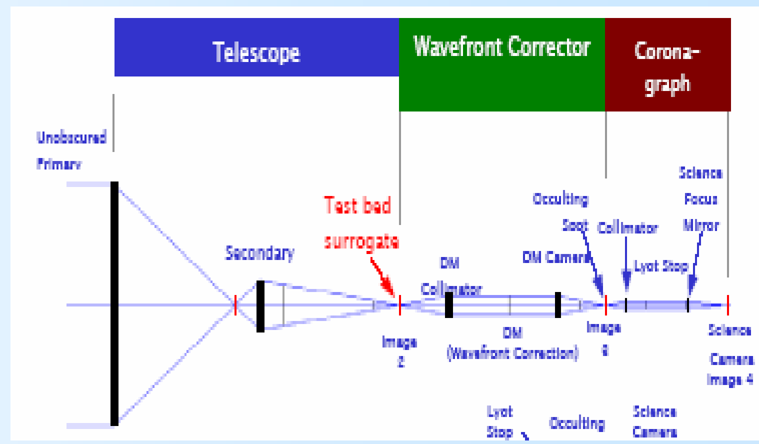
New direction for NASA science

- "We support NASA's Vision for Space Exploration…."
  - Moon, mars, infinity and beyond….
- Science activities shifting in this direction
  - Earth science measurements to support planetary science of Mars, Saturn, etc.
  - Astrophysics must also show relevance to this (not easy…)
- Terrestrial planet finding now a hot subject

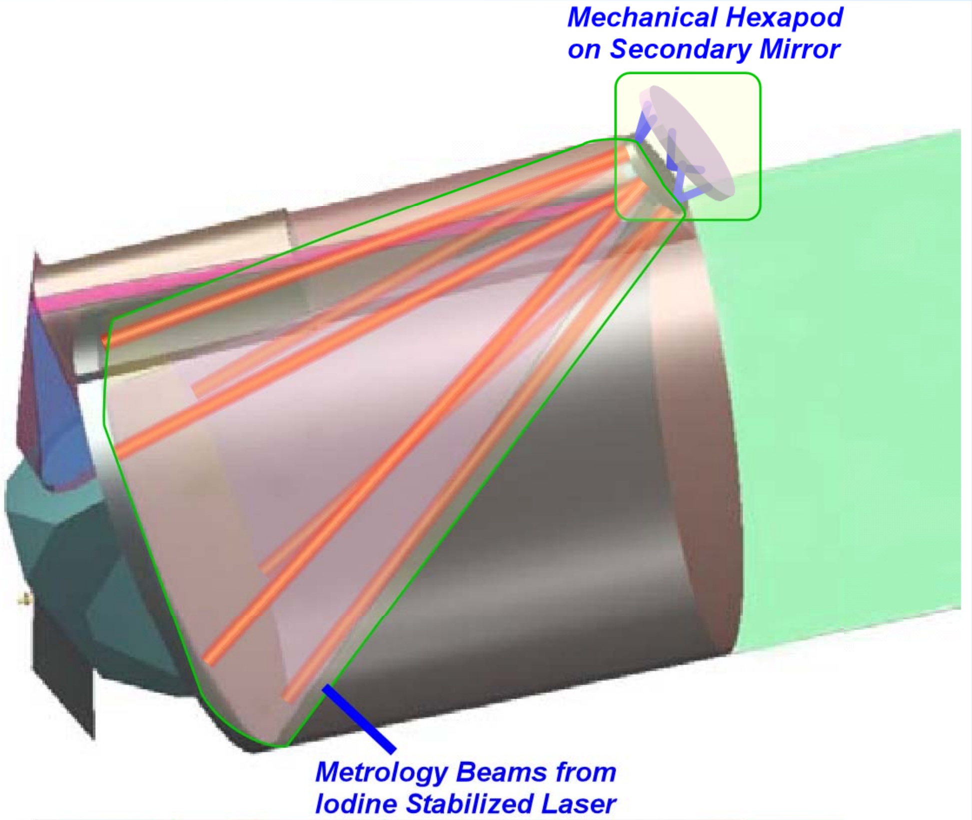


TPF – C : Search for Terrestrial Planets

- Coronagraph will look for reflected light from planet by blocking direct star light from nearby stars (< 15 pc)
- Spectroscopy of signal will give information on composition of planetary atmosphere
    - Water, CO_2, methane
- Contrast ratio of $1 : 10^9$
    - Telescope stability is very important

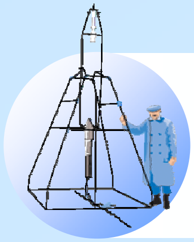


Interferometry in TPF-C



Stabilized laser and hexapod will control secondary mirror to 10^{-9} m, 10^{-9} radian over hour timescale

Metrology and control scheme will be developed on SPI



Summary

- Stabilized lasers will fly!
  - LISA 2013
  - TPF-C 2014

- Optical resonator and molecular transition under study
  - Noise requirements
  - Space qualification

- SPI testbed for low-frequency space interferometry
  - Iodine stabilization most useful