Seismic Noise and Seismic Isolation

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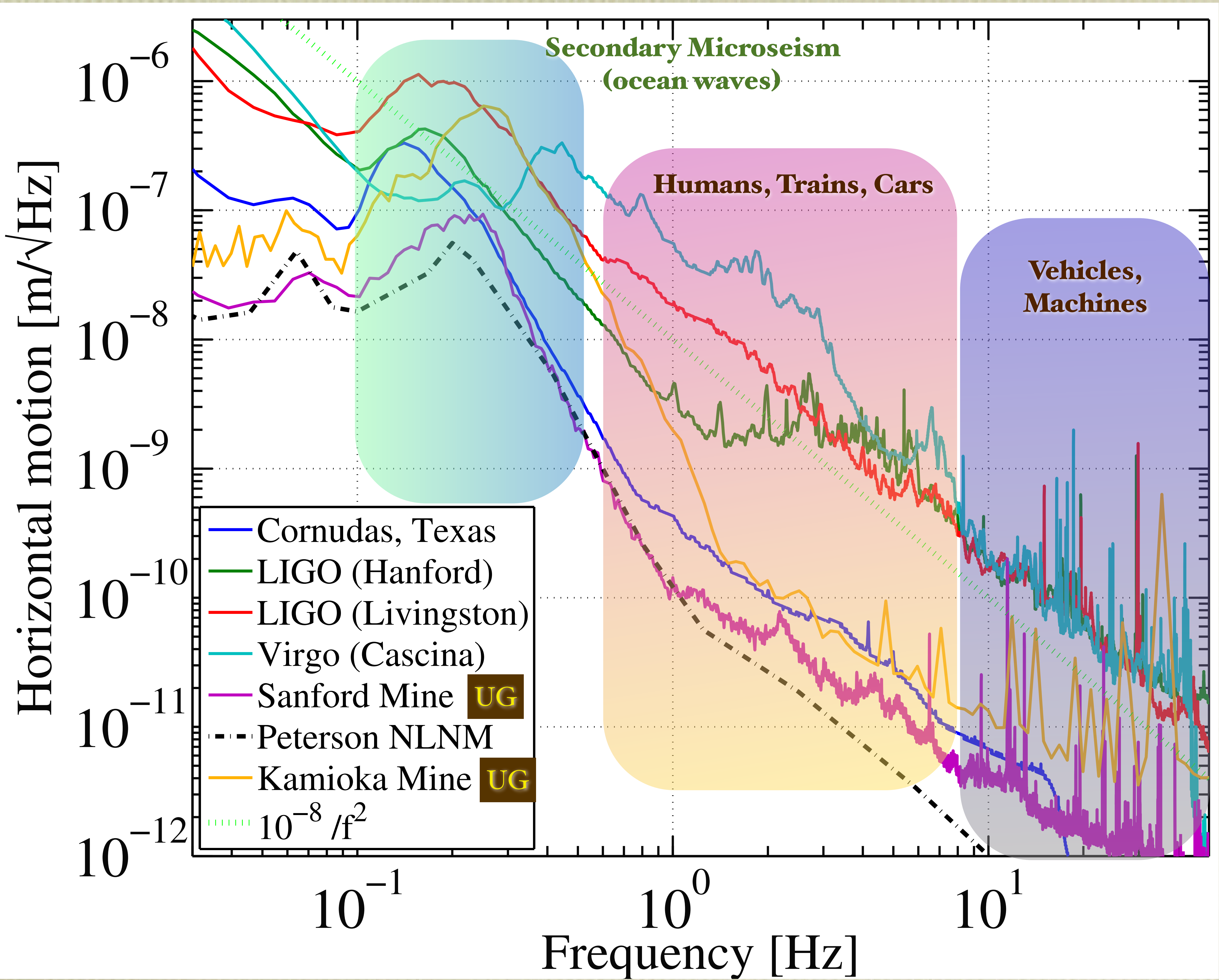
ICTS GW SChool, Indore, Dec 2013

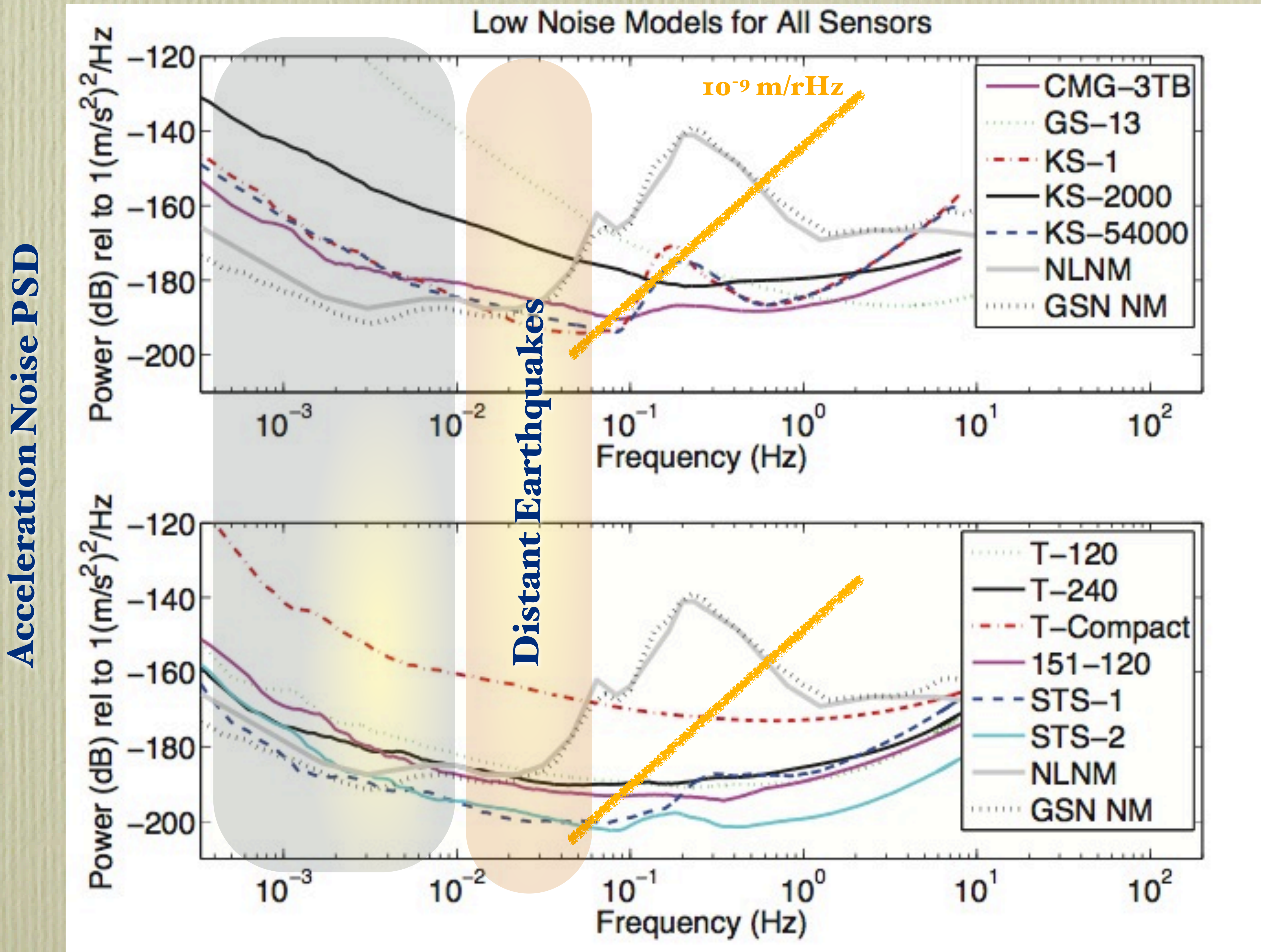
Outline

- Seismic Noise: What it is.
- Seismic Sensors: What is their problem?
- Seismic Isolation: Passive (Peter) and Active (via feedback and feedforward)

Seismic Noise

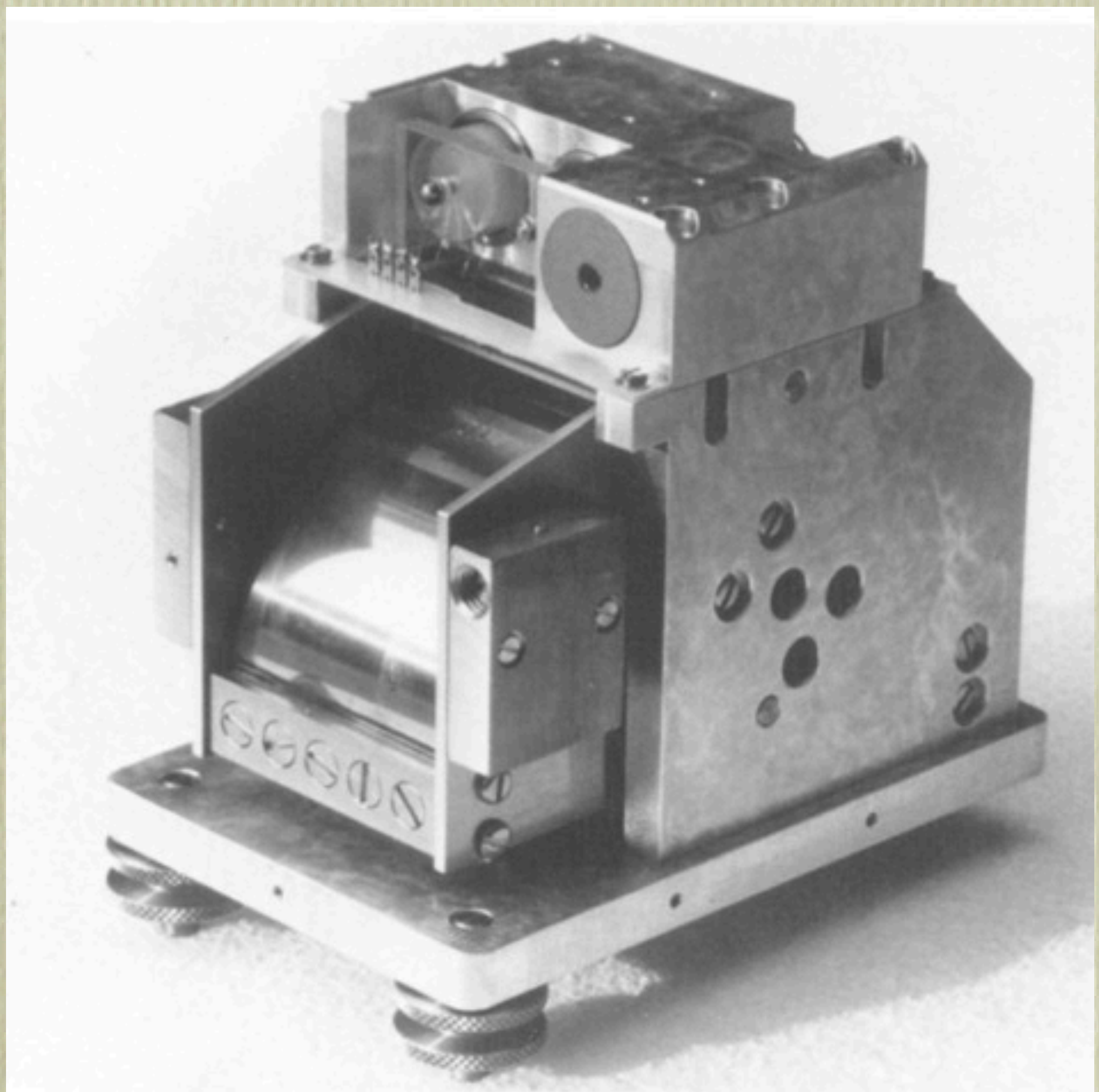


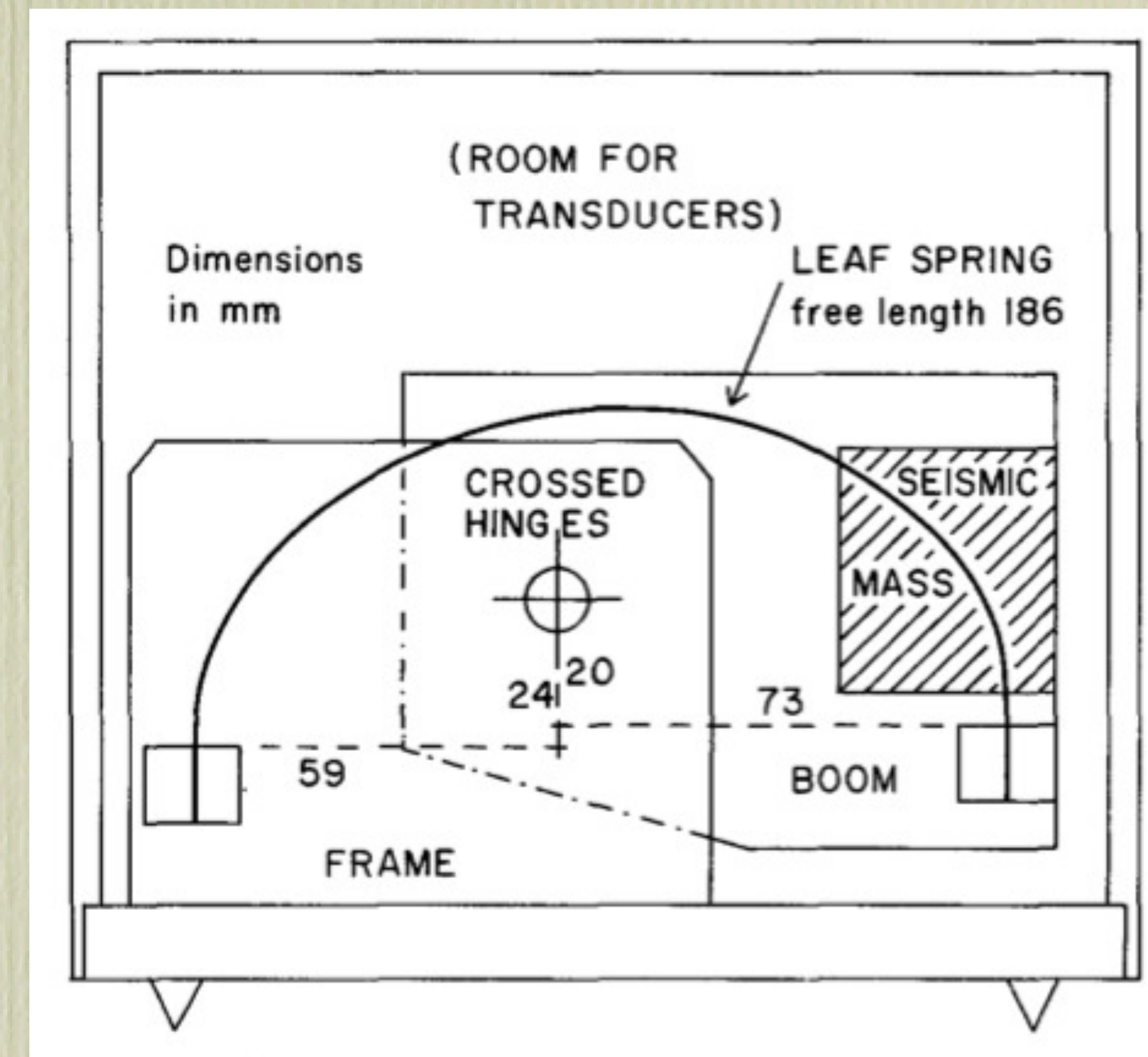
Seismic Sensors



Ringler & Hutt (2010)

Seismometers





Wielandt & Streckeisen (1982)

Seismometers

- For Low Frequencies: STS-2, T-240, STS-1,etc. (force feedback, triaxial, capacitive displacement sensors, $20k) or Lacoste-Romberg Gravimeters ("zero-length" springs, $100k)

- for 0.3-10 Hz, can use "geophones": no force feedback, velocity readout (magnet / coil), e.g. GS-13 ($14k), L-4C ($1k), ...

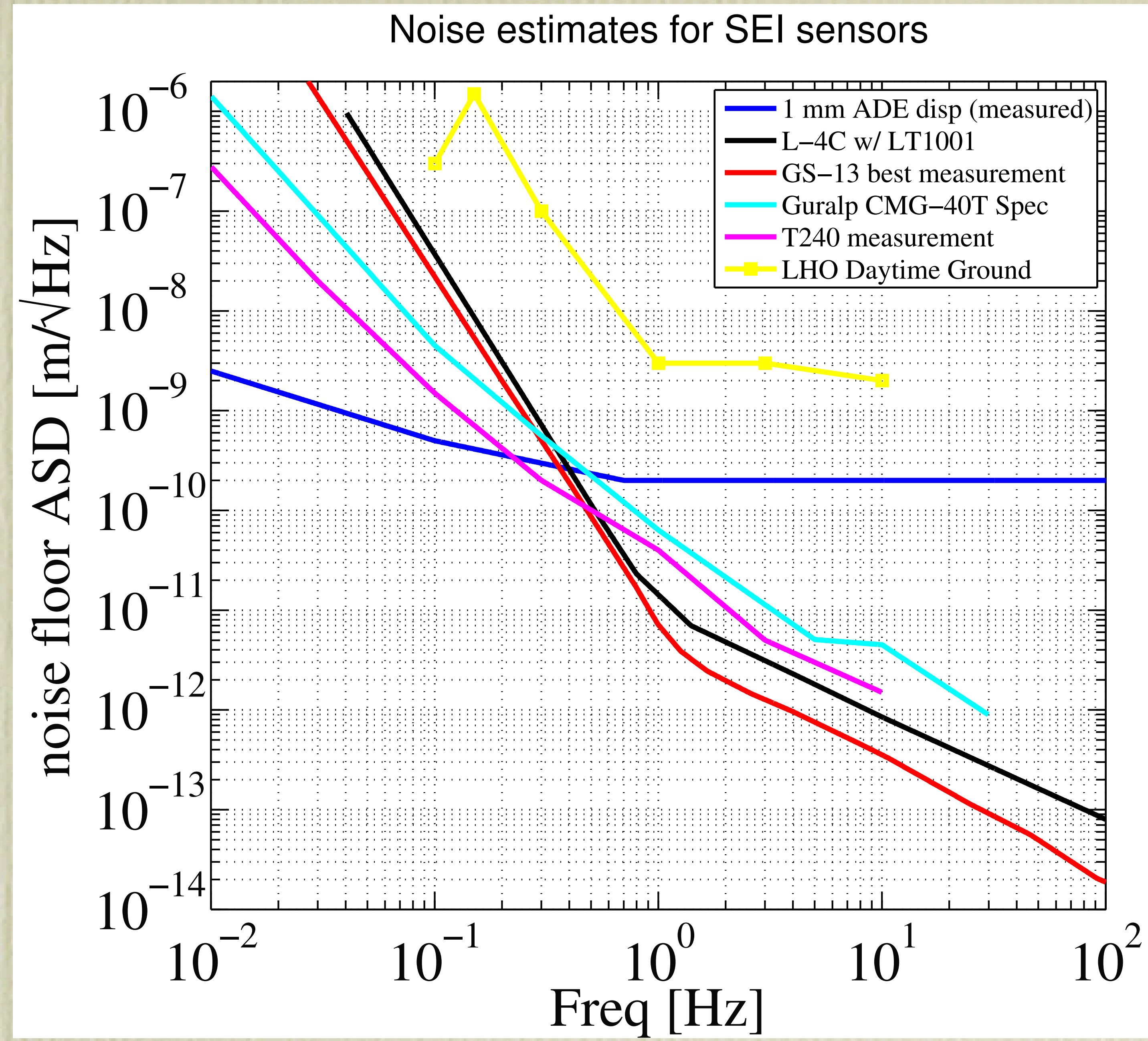
- For f > 3 Hz, accelerometers: ~0.1-1 kg with piezo strain sensor and charge amplifier ($100 -$1500)

Sensitivity Limits

- **Thermal Noise**: (cf. lecture by Peter Saulson, [2], Saulson, PRD (1990), Gonzalez and Saulson (1994, 1995)), losses from spring and from gas damping.

- **Electronics noise of readout** (Johnson noise of readout coil, readout preamp, voltage noise of capacitive bridge preamp)

- **Dirty effects**: pressure noise in the seismometer case, thermal gradients of the mounts, magnetic field couples to flexures, mechanical downconversion of acoustics due to hysteresis in the metal, etc.



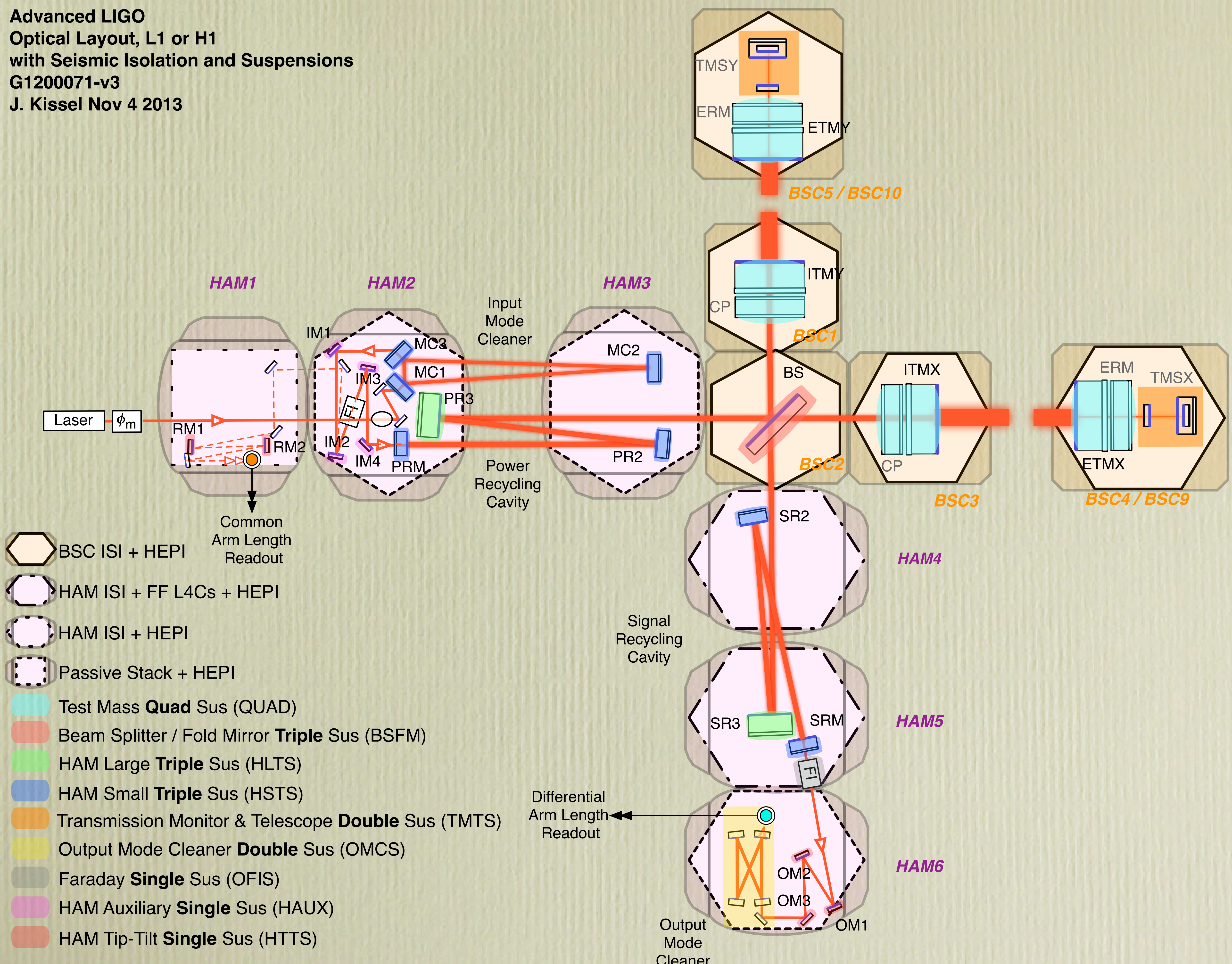
[1] M. J. Usher, C. Guralp, and R. F. Burch, Geophys J Int **55**, 605 (1978).

[2] M. Riedesel, J. Orcutt, and R. Moore, BSSA (1990).

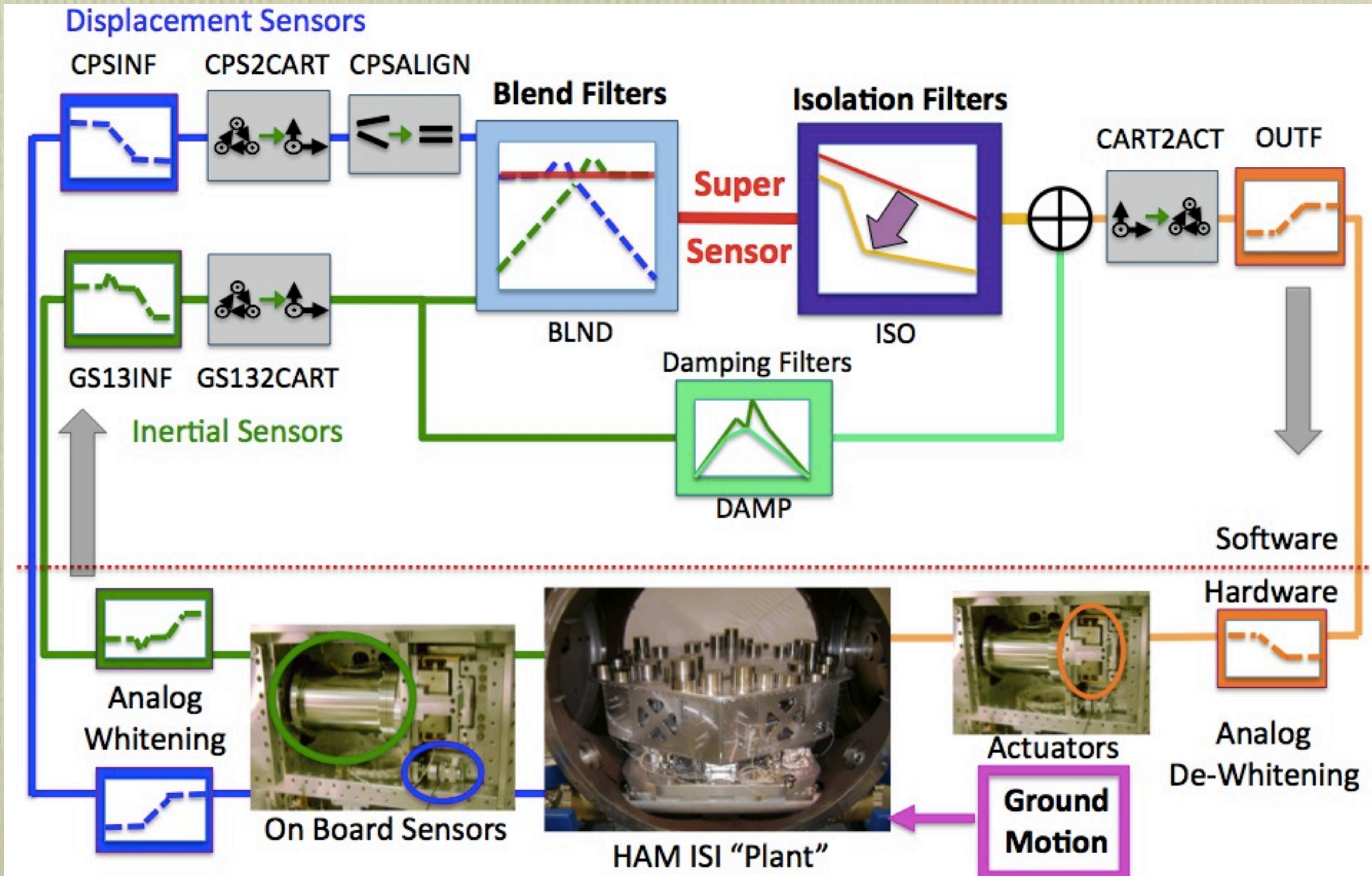
[3] P. Rodgers, Bulletin of the Seismological Society of America (1992).

Let's Design a Sensor

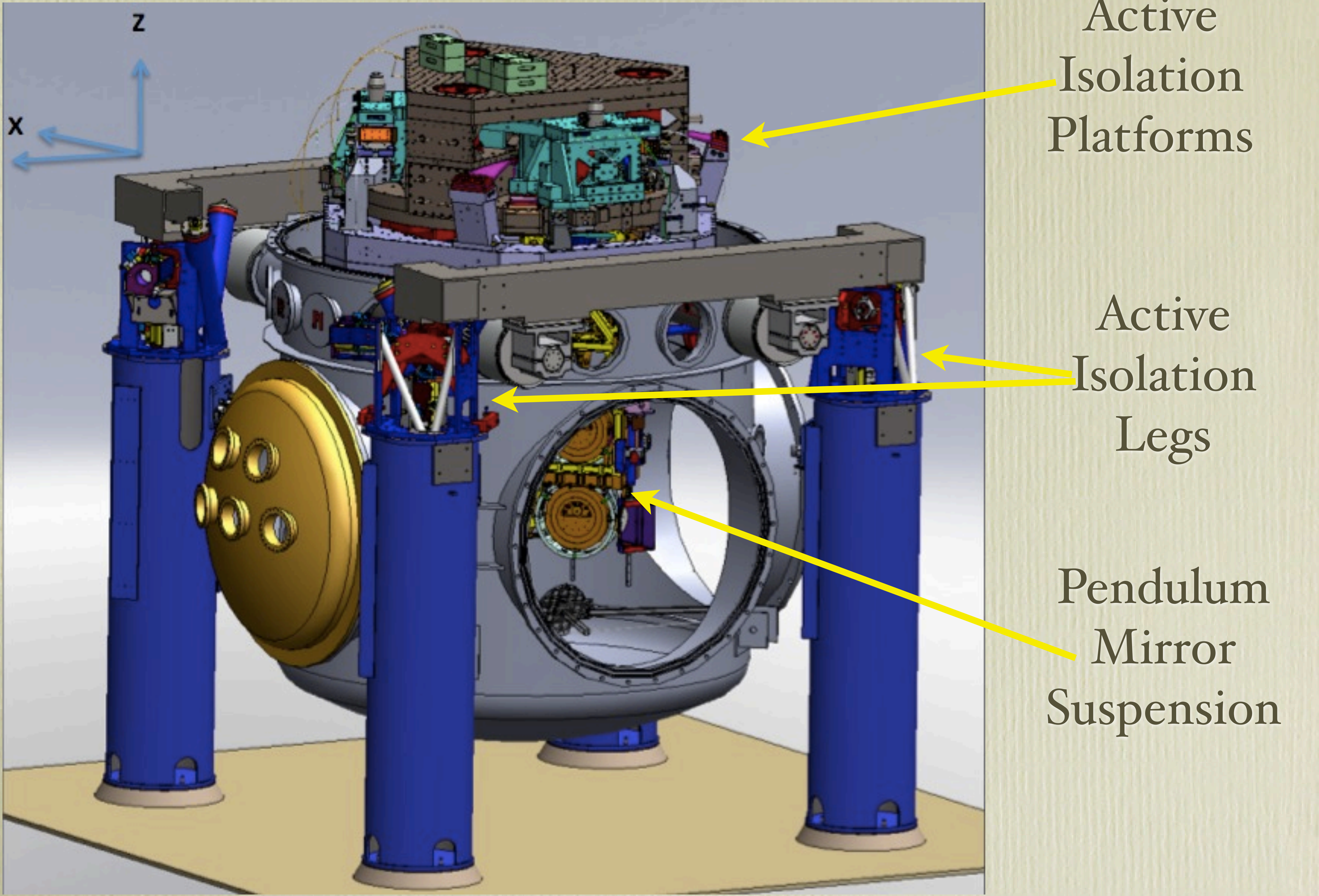
- Vertical Seismo, m ~1 kg, f0~1 Hz, Q ~ ?
- Shadow Sensor for displacement sensing (0.1 nm/rHz)
- Readout photocurrent (10 uA / mm) with AD743 transimpedance stage (+/- 15 V supplies).
- Calculate noise traces and sketch total displacement noise / compare with GS-13.


Advanced LIGO
Optical Layout, L1 or H1
with Seismic Isolation and Suspensions
G1200071-v3
J. Kissel Nov 4 2013
TMSY
ERM
ETMY
BSC5 / BSC10
ITMY
CP
BSC1
HAM1
HAM2
HAM3
Input
Mode
Cleaner
IM1
MC3
MC1
MC2
IM3
PR3
FI
Laser
ϕ_m
RM1
RM2
IM2
IM4
PRM
PR2
BS
BSC2
ITMX
CP
BSC3
ERM
TMSX
ETMX
BSC4 / BSC9
Power
Recycling
Cavity
Common
Arm Length
Readout
SR2
HAM4
Signal
Recycling
Cavity
SR3
SRM
HAM5
FI
Differential
Arm Length
Readout
OM2
OM3
OM1
HAM6
Output
Mode
Cleaner
BSC ISI + HEPI
HAM ISI + FF L4Cs + HEPI
HAM ISI + HEPI
Passive Stack + HEPI
Test Mass Quad Sus (QUAD)
Beam Splitter / Fold Mirror Triple Sus (BSFM)
HAM Large Triple Sus (HLTS)
HAM Small Triple Sus (HSTS)
Transmission Monitor & Telescope Double Sus (TMTS)
Output Mode Cleaner Double Sus (OMCS)
Faraday Single Sus (OFIS)
HAM Auxiliary Single Sus (HAUX)
HAM Tip-Tilt Single Sus (HTTS)

Adv LIGO Seismic Overview

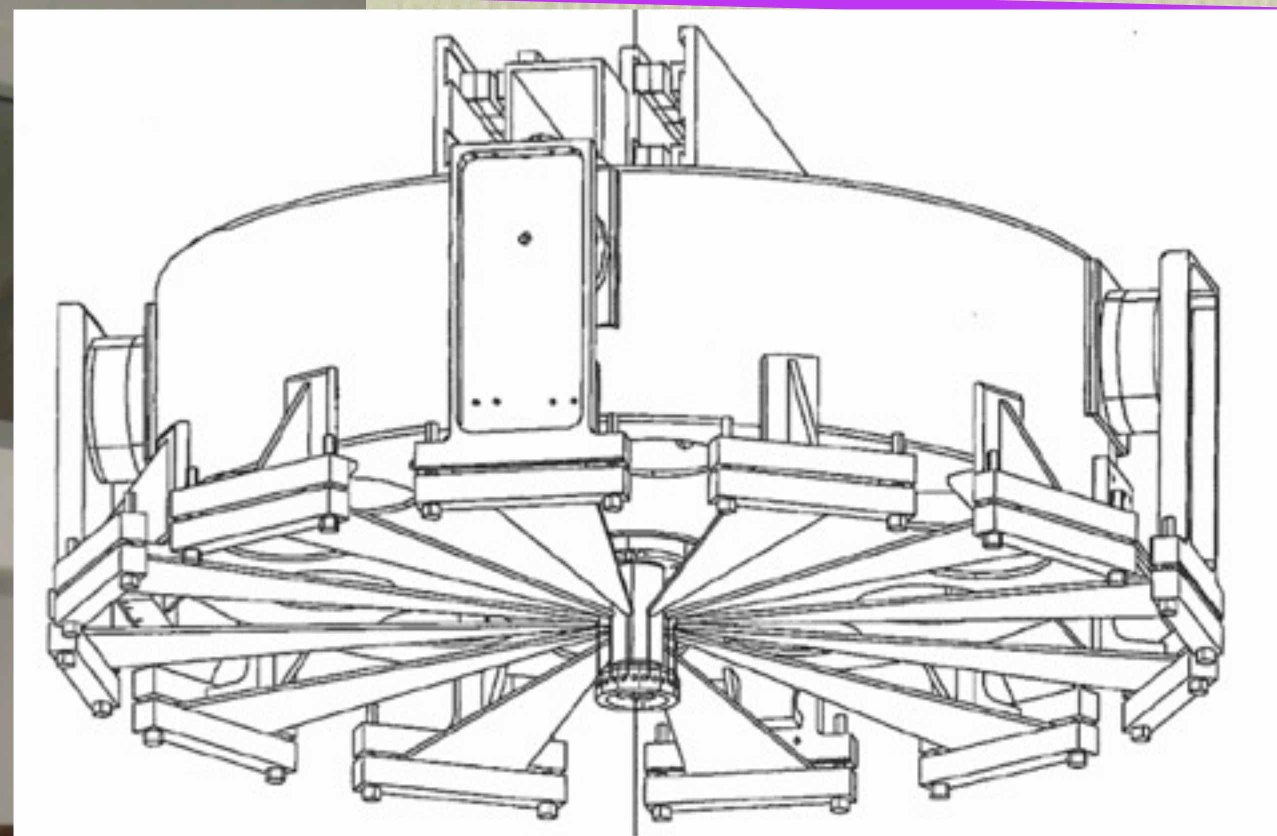


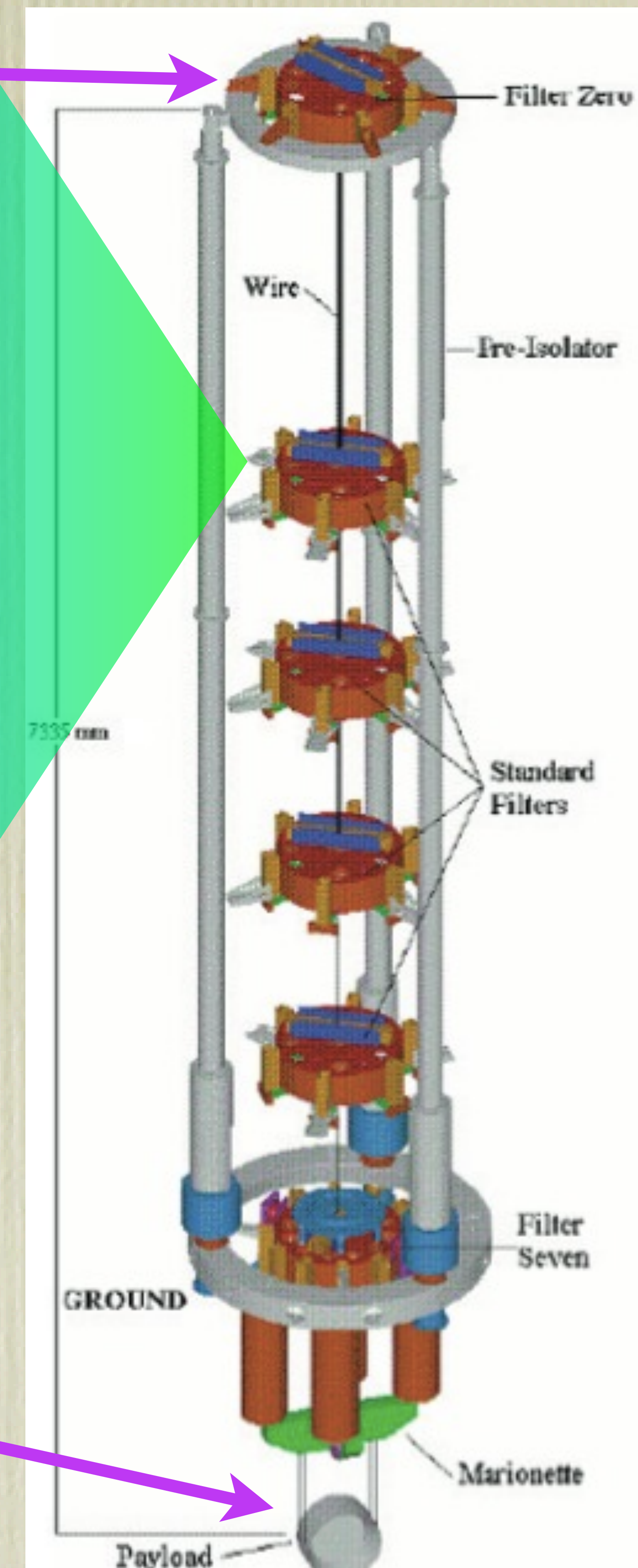
https://dcc.ligo.org/LIGO-G1100431/public


z
x
Active Isolation Platforms
Active Isolation Legs
Pendulum Mirror Suspension

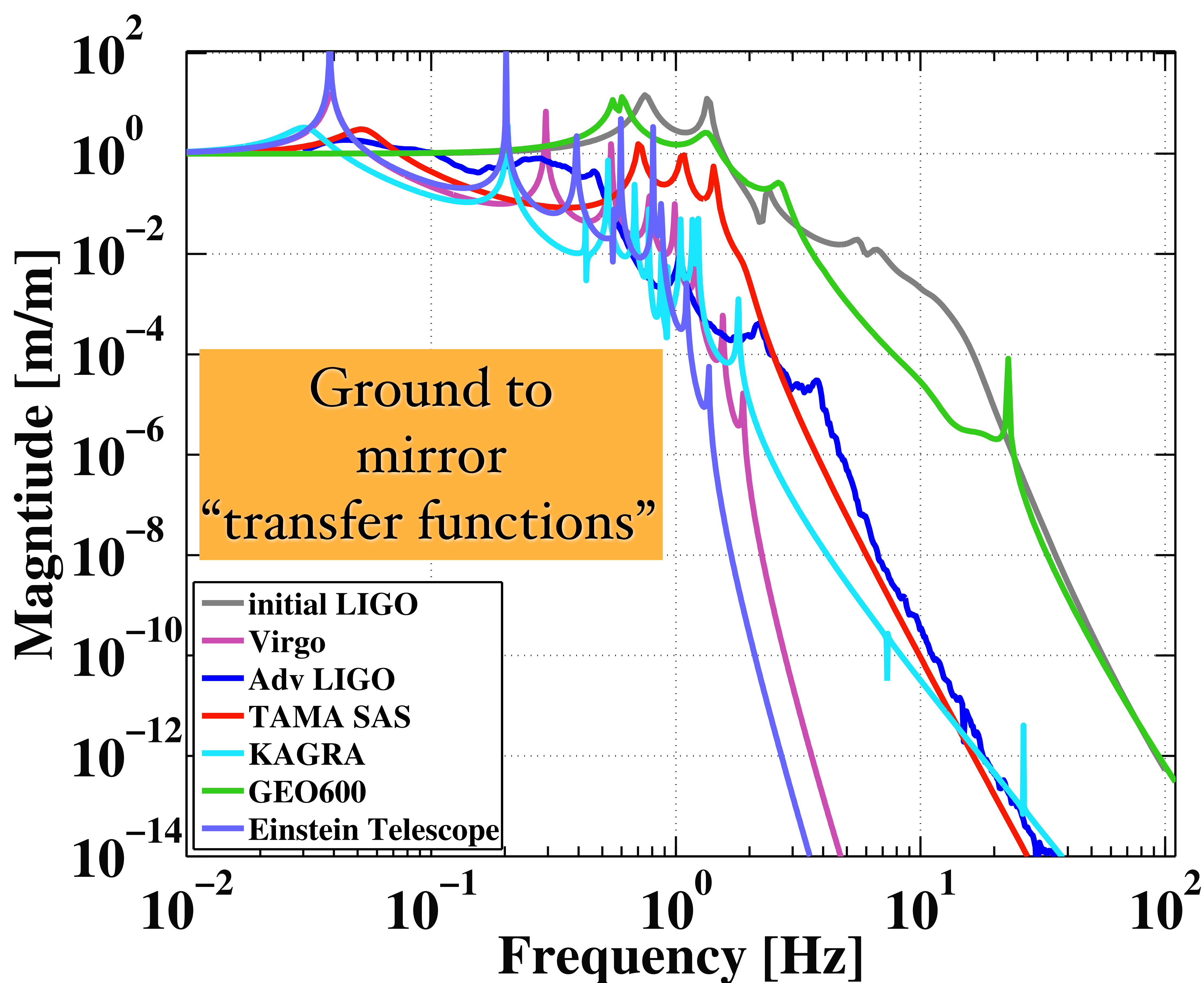
What's Wrong with Pacifism?

(OR why will KAGRA,Virgo,~~AIGO~~ want passive and LIGO will use active???)





Identify the 5 biggest differences...



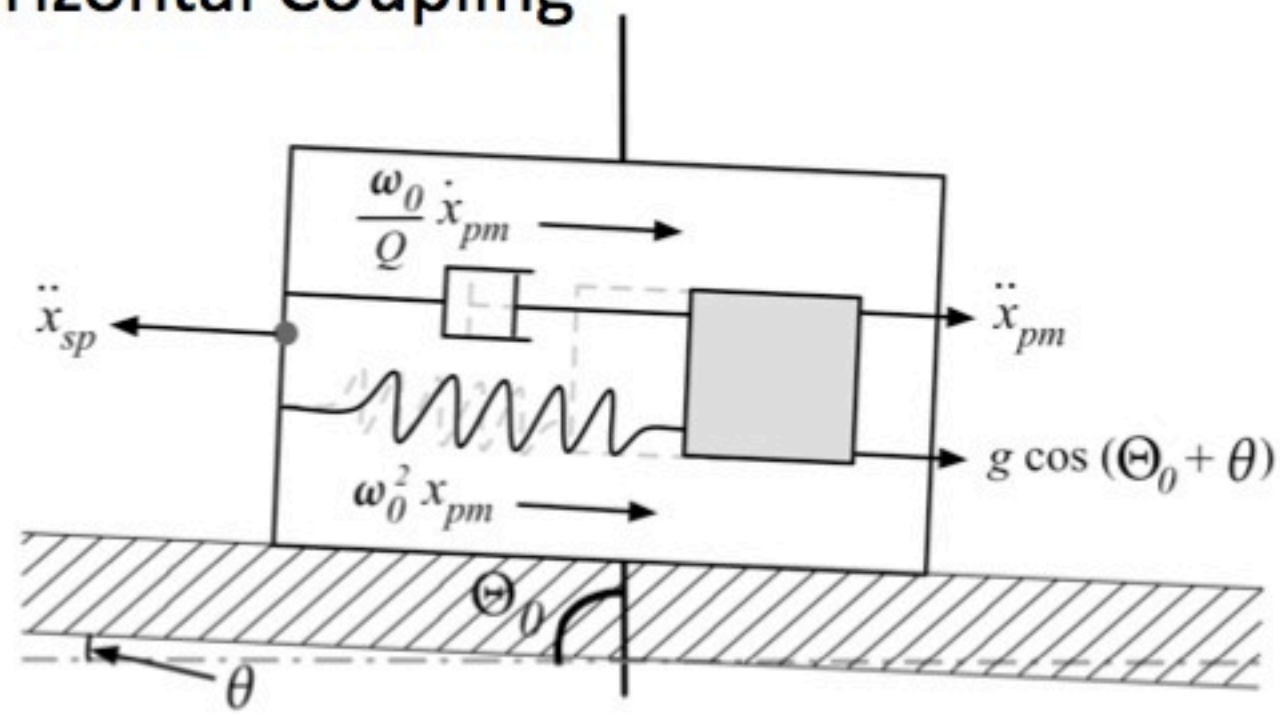
Tilt-Horizontal Problem

Tilt – Horizontal Coupling

- Fundamental property of a horizontal inertial sensor

$$x_{pm}^{(h)} \propto \left(x_{sp}^{(h)} - \frac{g}{\omega^2}\theta \right)$$

- Effect dominant at low frequency (< 0.5 Hz)



- Ring Laser Gyro (MIT: Ezekiel, New Zealand: Stedman, Caltech: Korth)
- Pairs of Vertical Seismometers (Stanford/Debra)
- Mercury Beam Balance / Bubble Level
- Beam-Balance / See-Saw (Desalvo, Giazotto, UW: Krisha, Gundlach)
- Fiber Ring Gyro
- Tilt-Free Seisometer (MIT: Evans/ Matichard, Virgo: Giazotto)
- Optical "Walk-Off" Lever (UWA: Blair)
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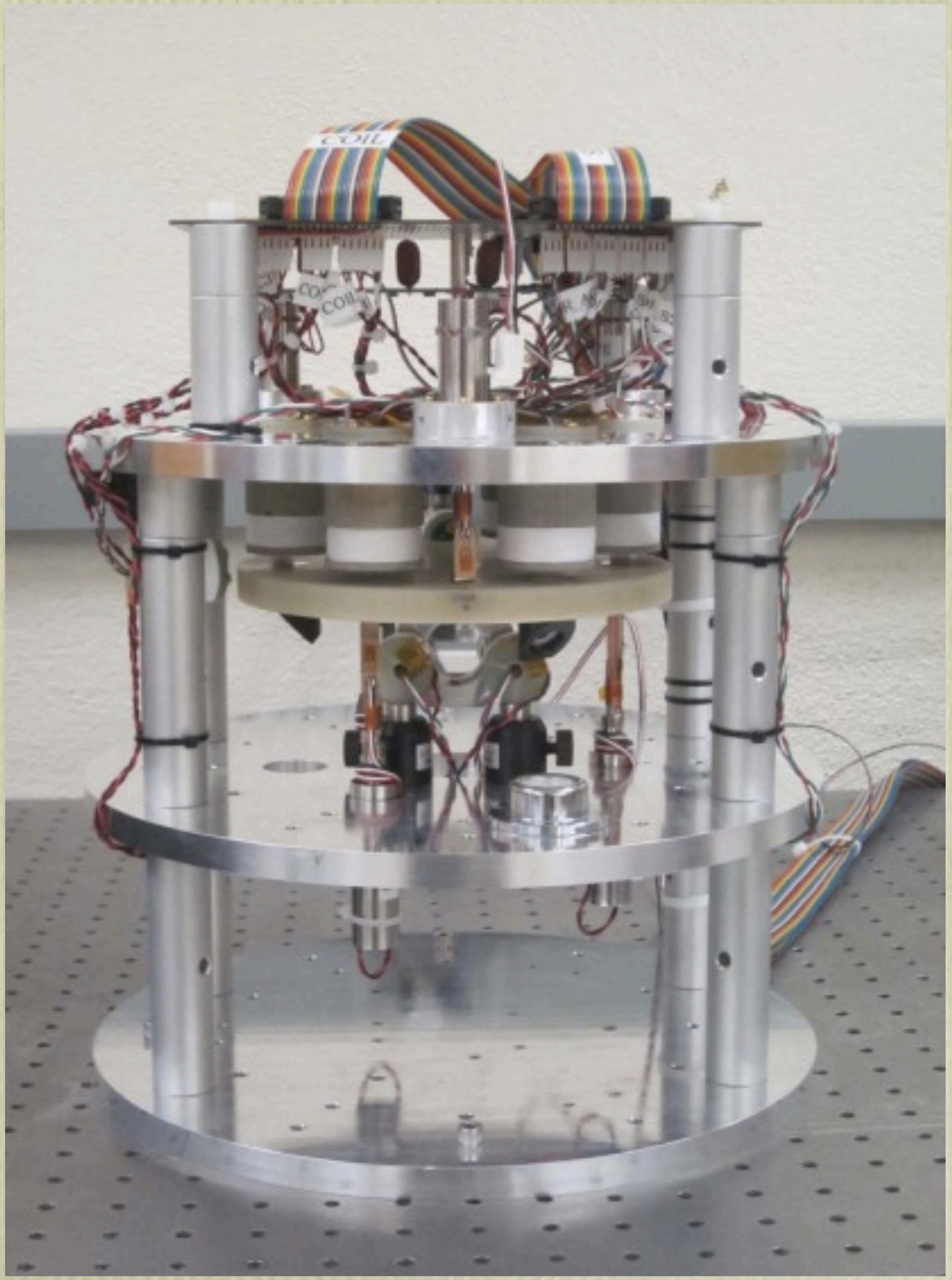
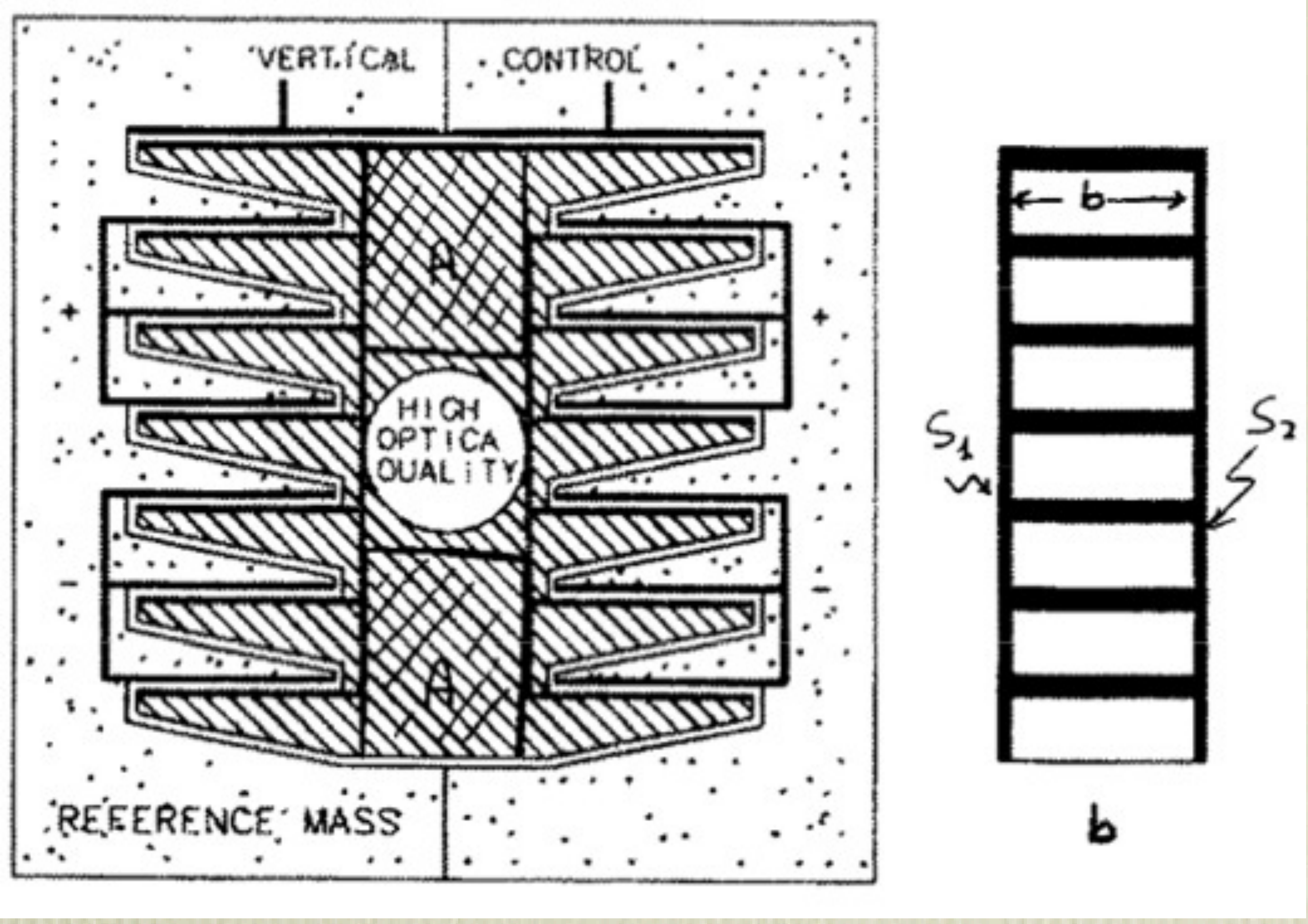
Electro-Magnetic Suspension



H. Miao (2013)

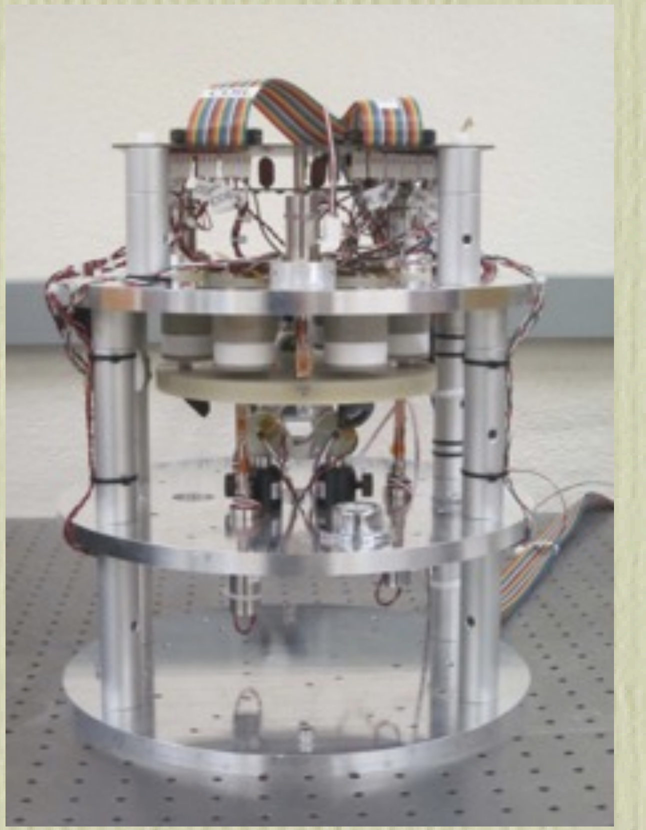
1. EM suspensions eliminate suspension fiber and thereby, the thermal noise

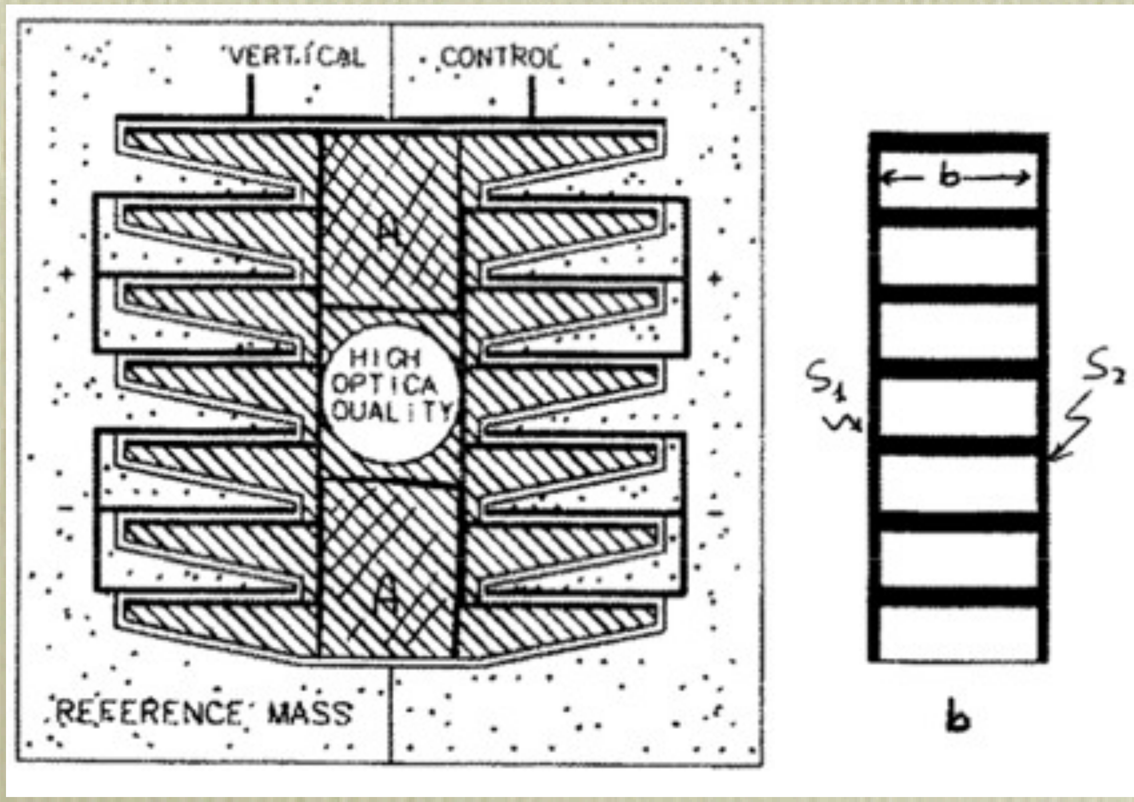
2. EM levitation can be soft, low resonant frequency, so infinite isolation



A. Giazotto (1998)

Electro-Magnetic Suspension





1. EM suspensions eliminate suspension fiber, but there is still loss associated with the spring. Yes, even superconducting magnets.
2. EM levitation can be soft, but softness is limited by stability. Earnshaw's theorem...
3. Earnshaw says 1 DOF will be unstable. Need low noise position sensors for damping.
4. Residual EM dipoles, quadrupoles, ... allow coupling of environmental fields.