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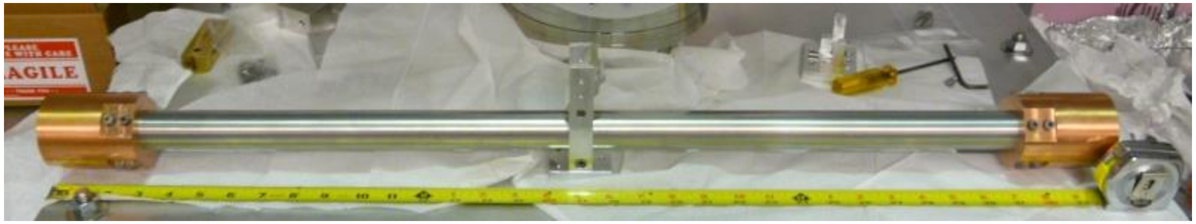

Improving seismic isolation in Advanced LIGO using a ground rotation sensor

04/16/2016

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for

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aLIGO – SEI team

LIGO-G1600083

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- Introduction: Why tilt affects LIGO
- BRS at LIGO Hanford and Tilt Data
- Next Gen/Compact BRS
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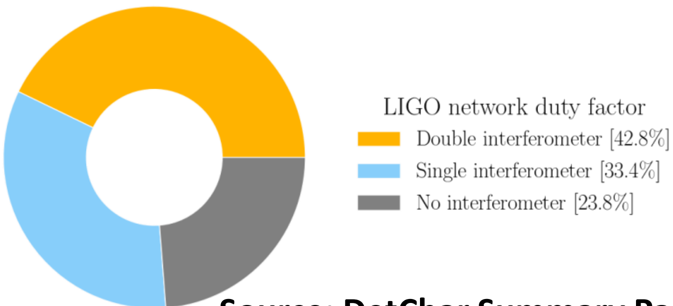
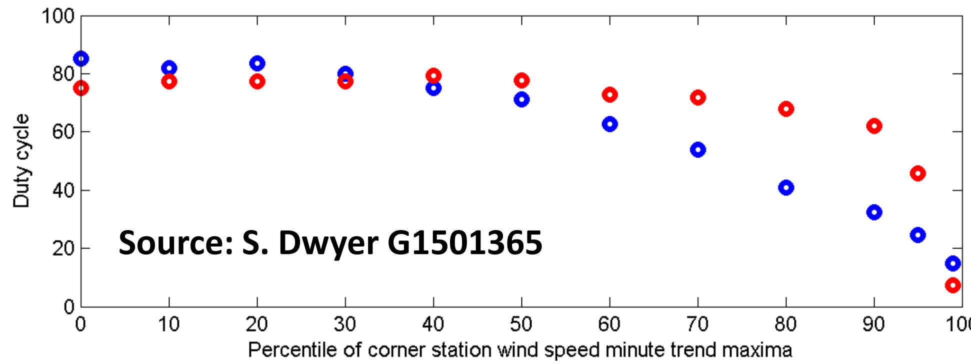
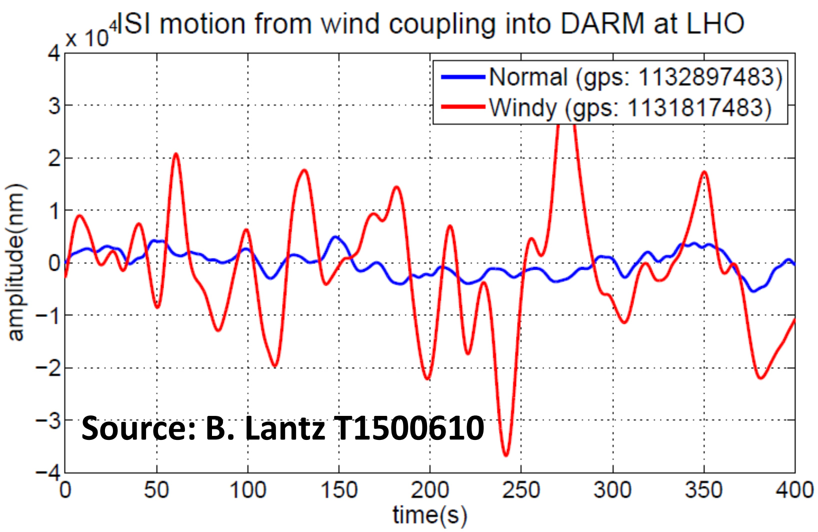
Introduction

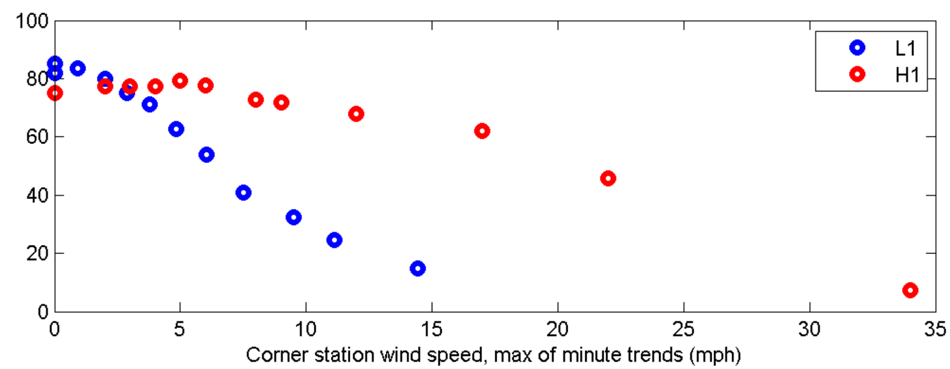
Tilt-problem limits duty cycle of detectors



Source: DetChar Summary Pages



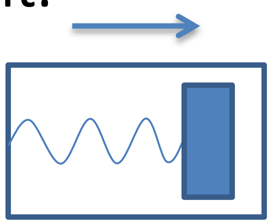




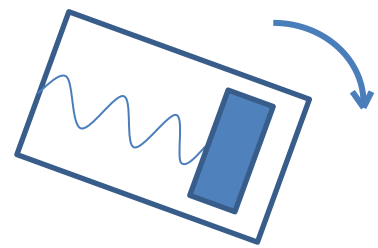
- Earthquakes, High Wind and High Microseism cause significant down-time of both detectors.
- All are primarily related to the problem of <u>tilt-horizontal coupling</u> producing too much ISI motion.

Tilt versus Horizontal displacement

- Conventional seismometers and tiltmeters cannot differentiate between horizontal displacement and ground tilt.



$\delta x \propto a_x$



$\delta x \propto g\theta$

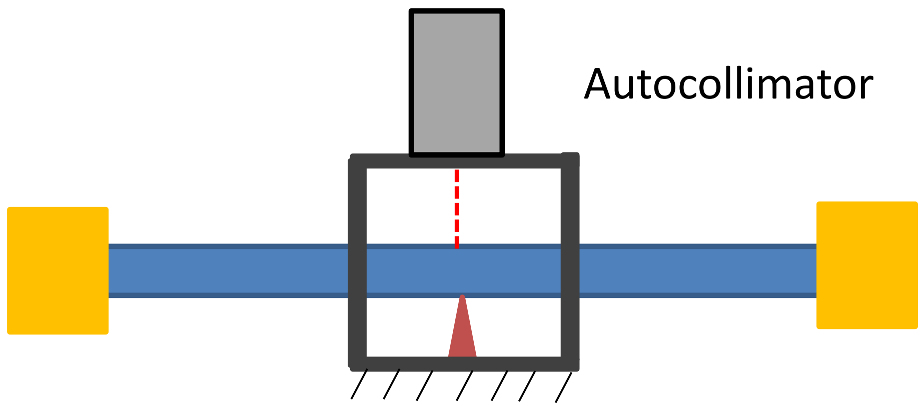
Tilt response to horizontal displacement response for <u>all</u> seismometers = $-g/\omega^2$

$\Rightarrow$ Tilt is confused with horizontal motion at low frequencies (below ~ 0.1 Hz).

<u>Solution</u>: Inertial rotation sensors, Tilt-free seismometers or Ring-laser gyroscopes…

Beam Rotation Sensors

BRS Concept

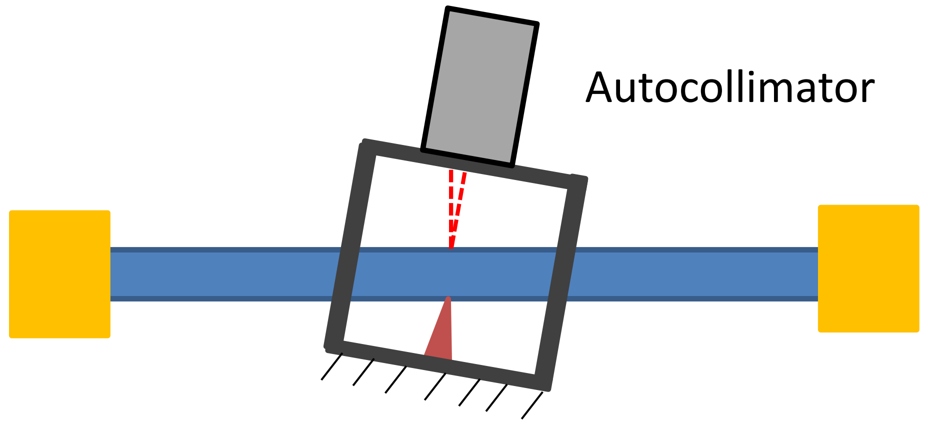


Principle:

- Ground tilt is measured by measuring angle between ground and low frequency beam balance.
- Horizontal acceleration can be rejected by locating center of mass at the pivot.

Venkateswara, Krishna, et al. "A high-precision mechanical absolute-rotation sensor." Review of Scientific Instruments 85.1 (2014): 015005.

BRS Concept



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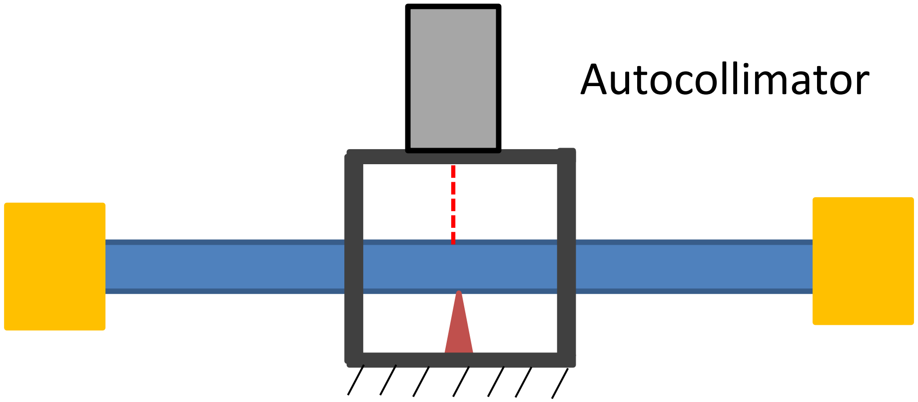
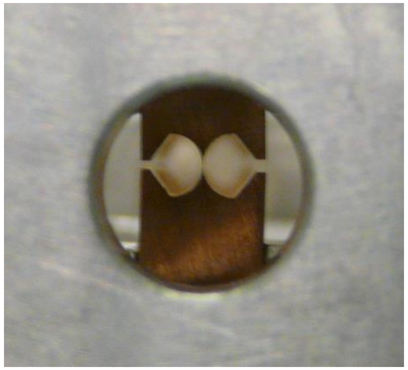
BRS Parameters





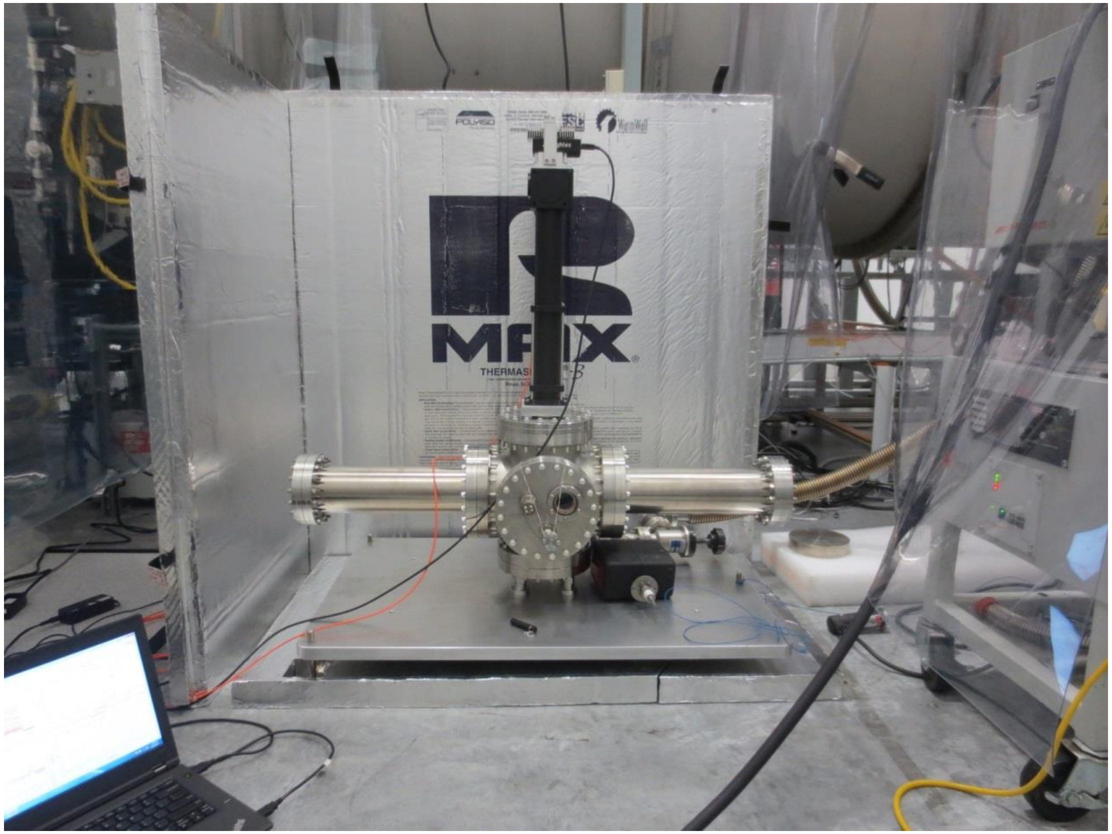
10-25 μm-thick
Cu-Be Flexures

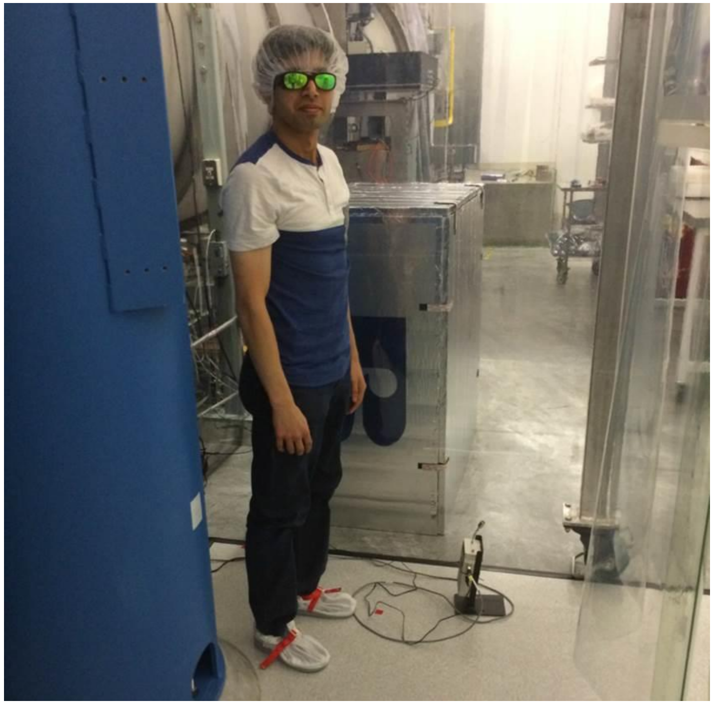
Mass	4-5 kg
Length	0.9 m
Moment of Inertia *I*	0.6 kg m^2
Flexure stiffness	10^{-3} N m
Quality factor	2000-3000
Distance between pivot and center of mass	Can be tuned to less than 1 μm

Displacement rejection ratio

$$\frac{\hat{\theta}}{\hat{x}_g} \approx \frac{M\delta}{I} \approx 0.00001[rad/m]$$

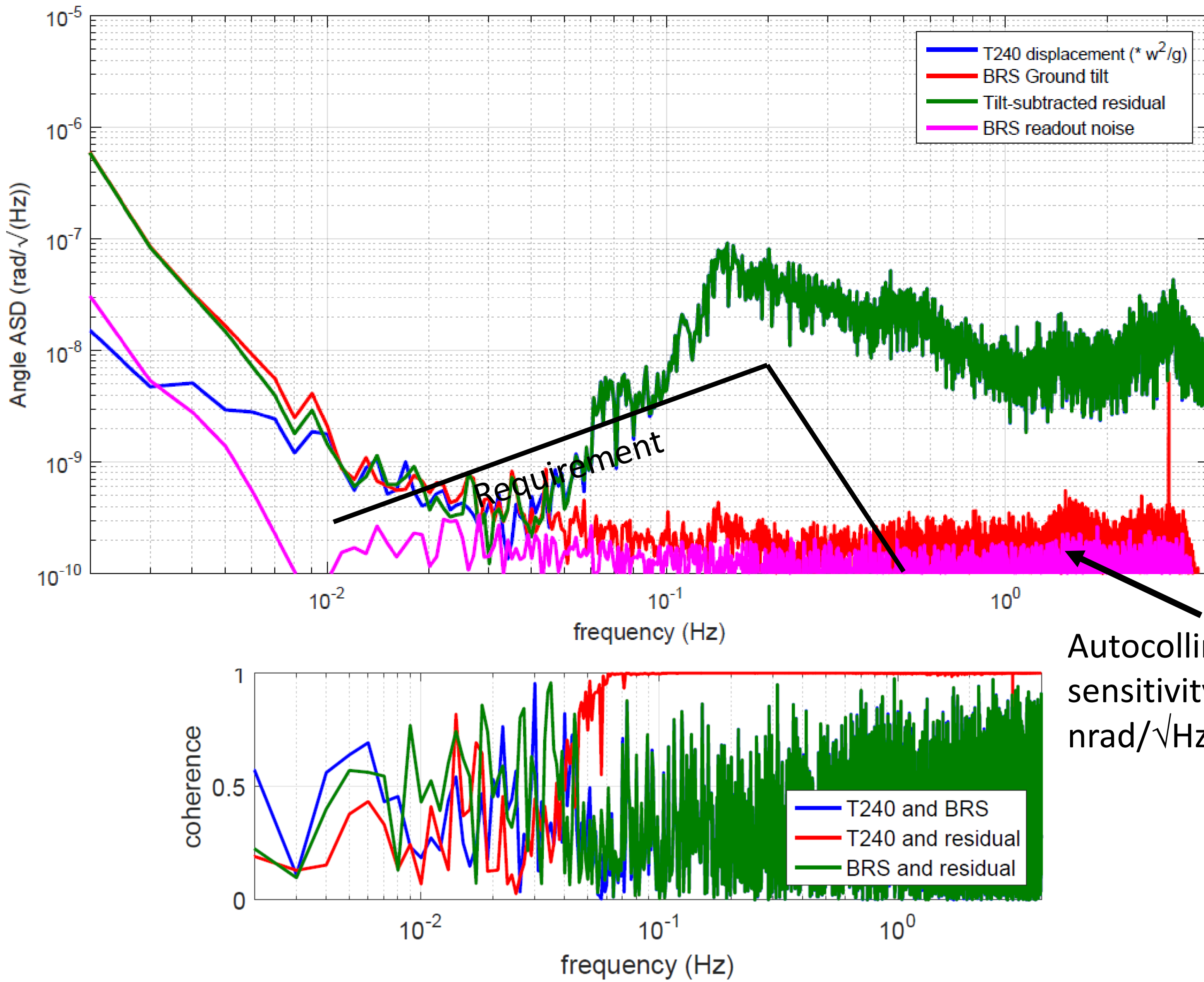
Installation at EX VEA





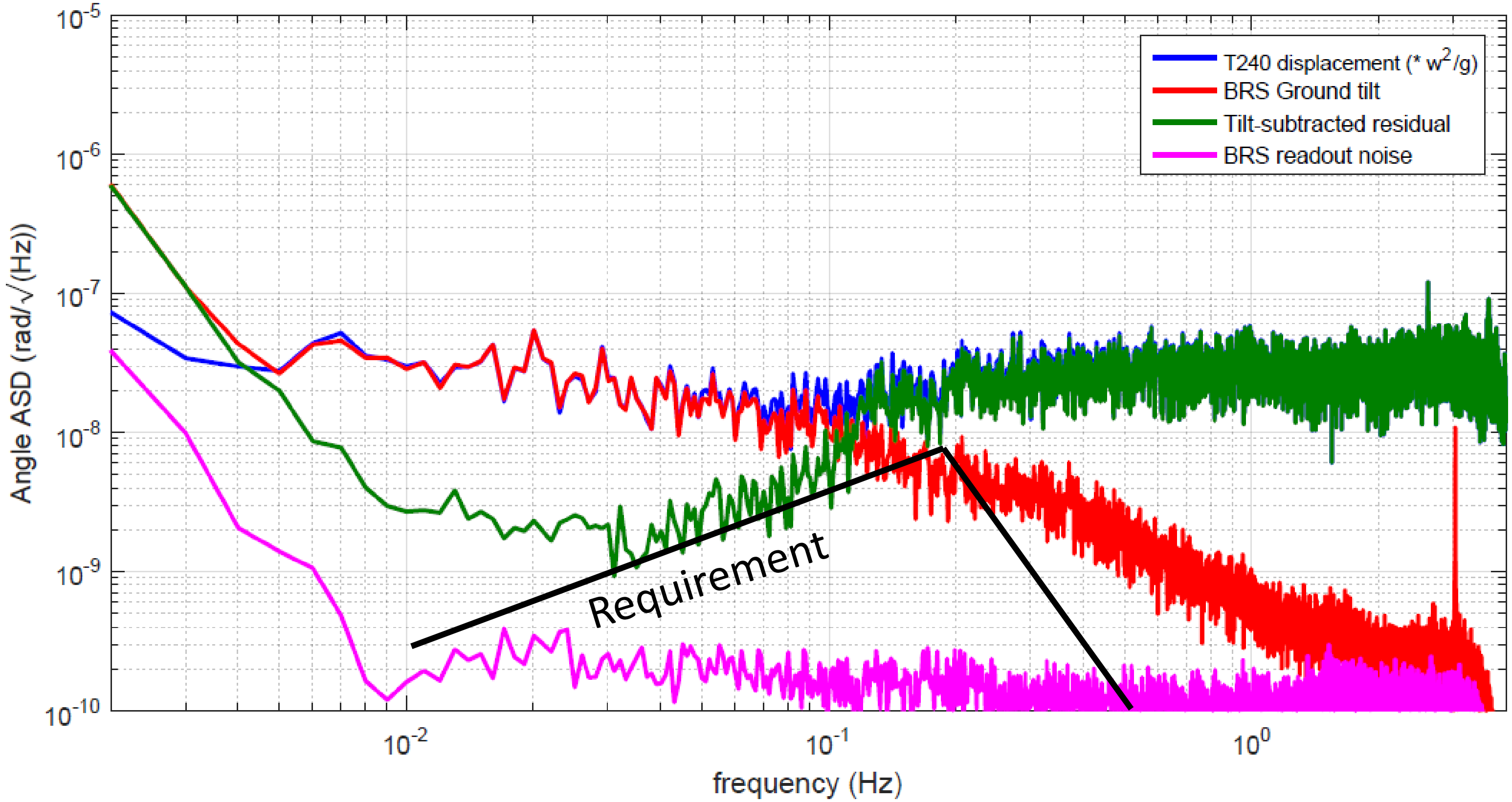
Ref: LHO 13250

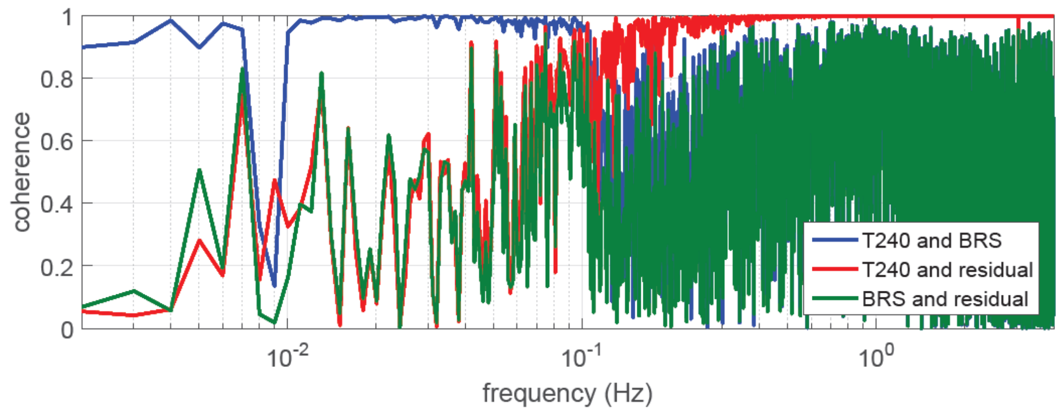
Ground tilt during low wind speeds



Autocollimator sensitivity is ~0.1 nrad/√Hz

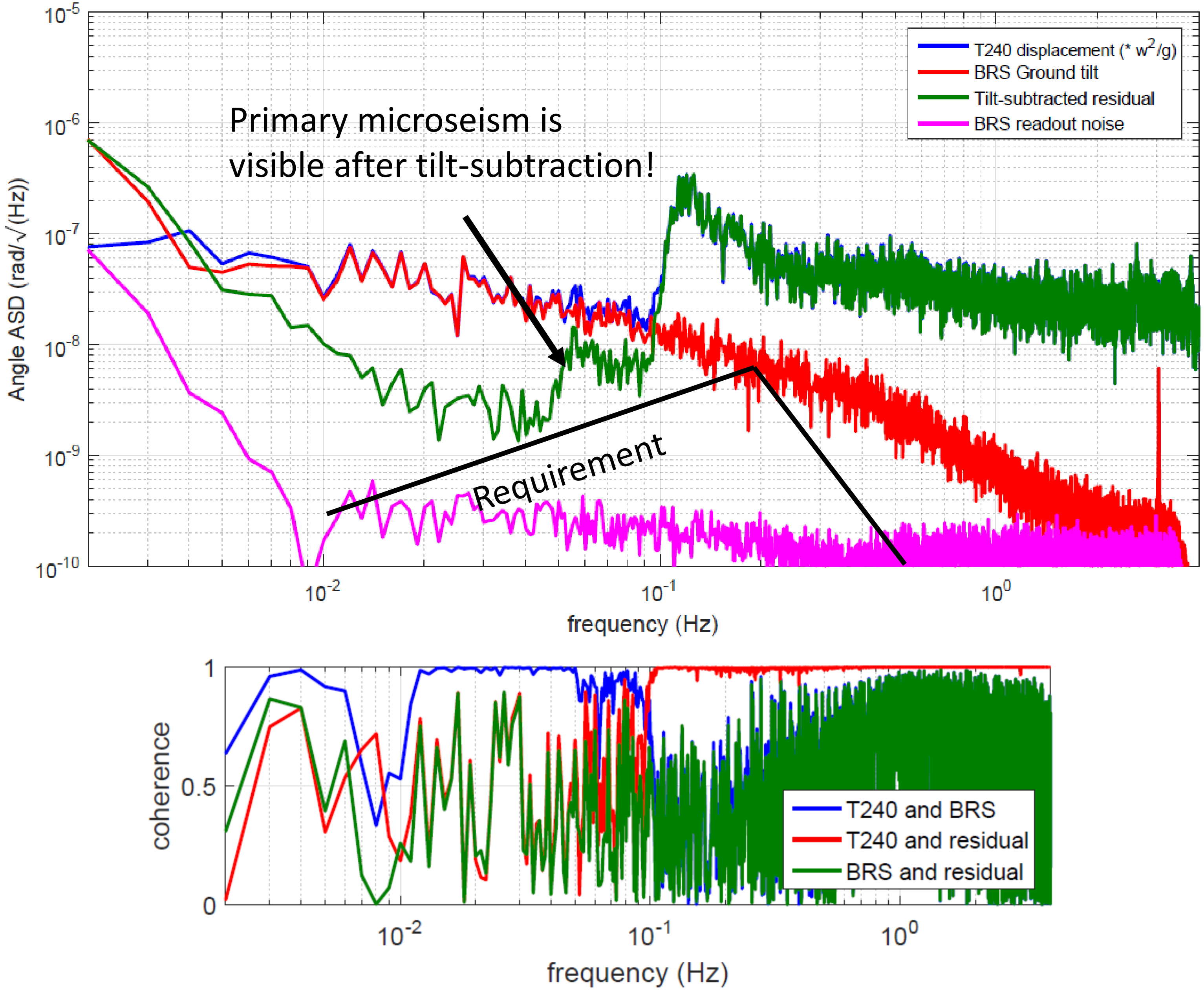
Ground tilt during 20-30 mph winds



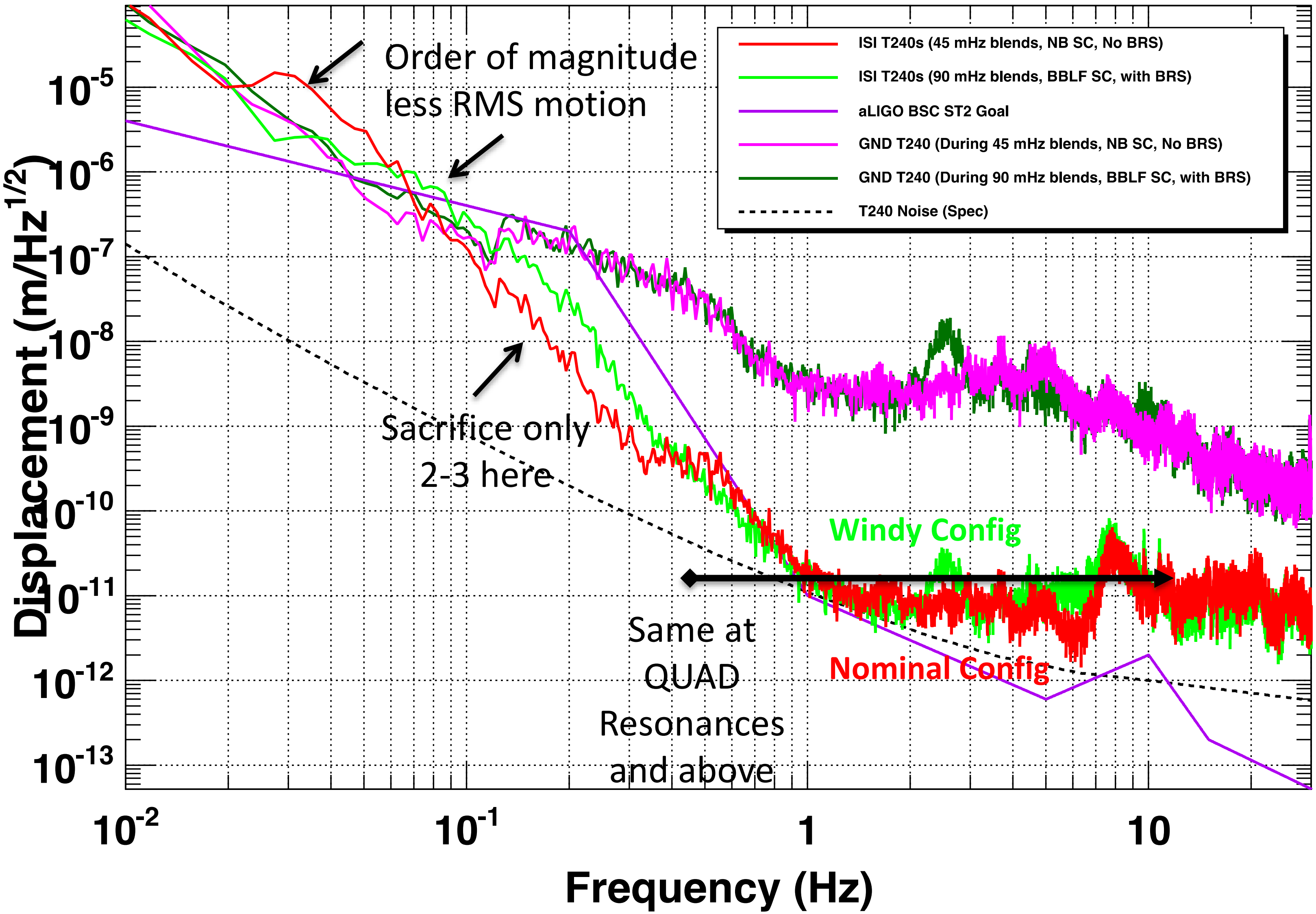


High coherence between ground seismometer and BRS

Second example

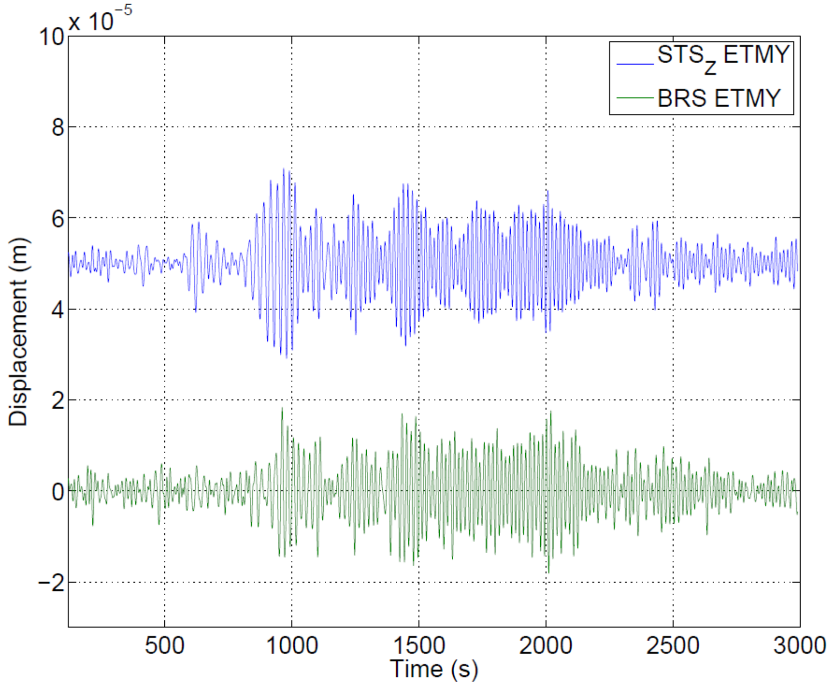


Improving Isolation



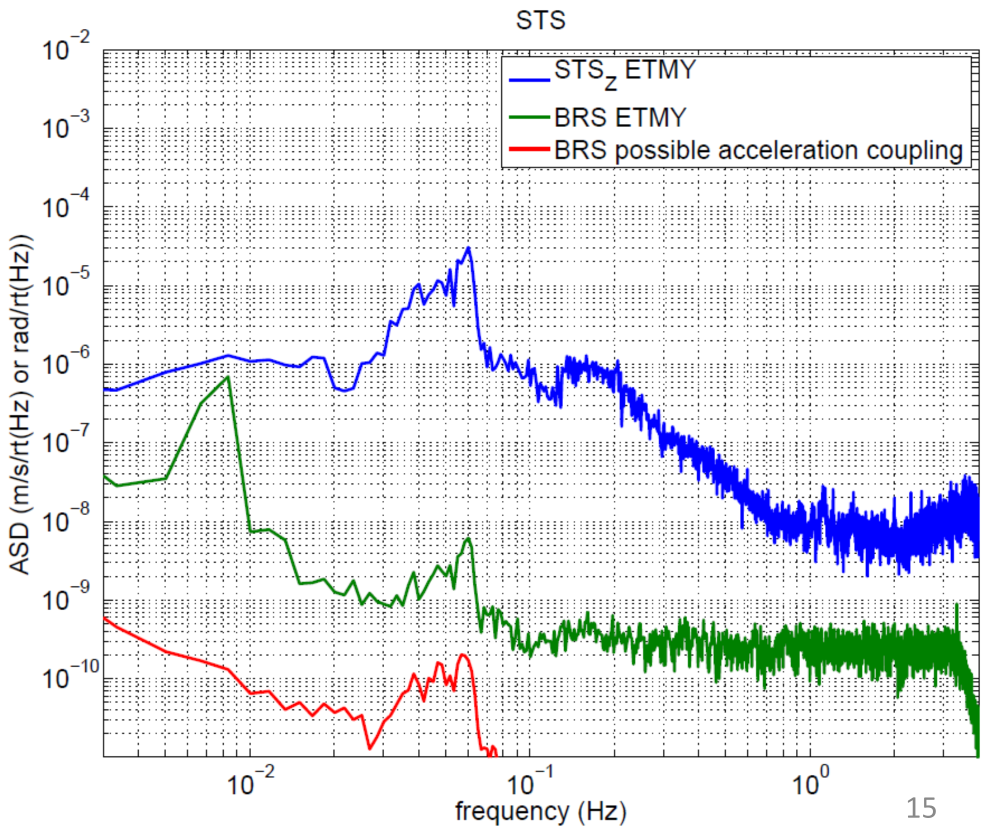
Source: J. Kissel, G1500475

Ground tilt from M6.7 Earthquake near Australia



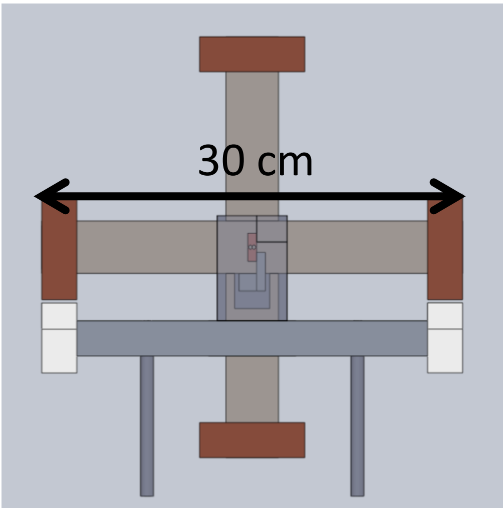
Band-passed time-series signals

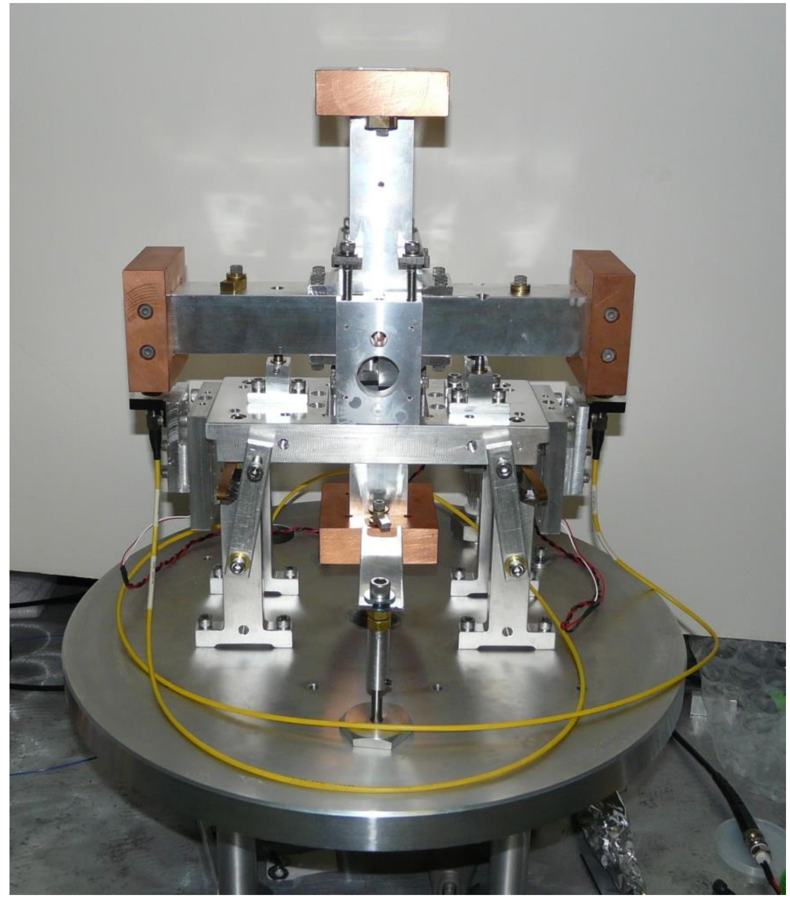
ASD of ground seismometer and BRS Data.



Next Gen/Compact BRS

Compact-BRS

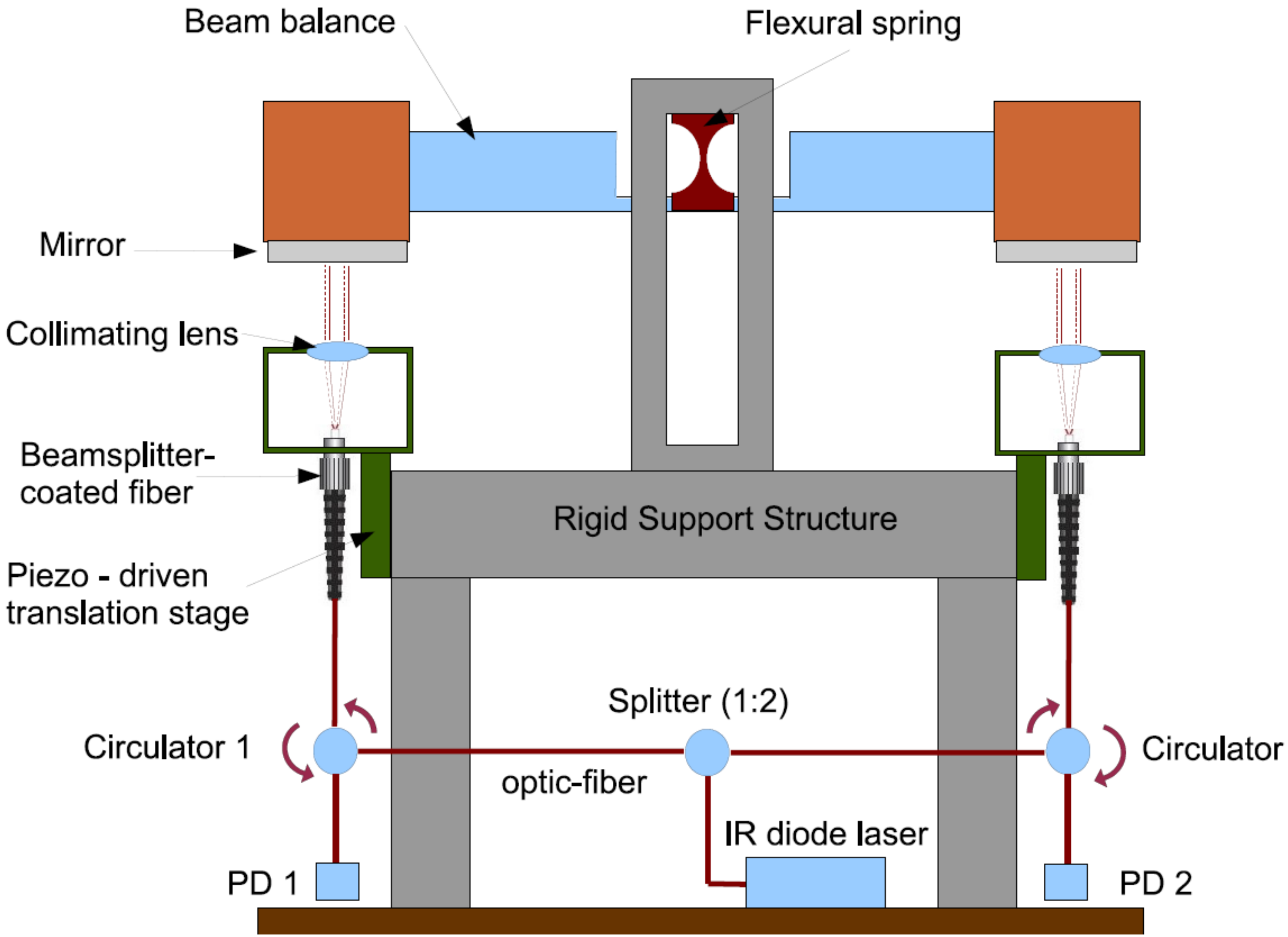




New features

1. Cross Shape (~0 quadrupole moment) ensures first order insensitivity to gravity gradient noise.
2. New compact interferometric readout with ~10X better sensitivity.

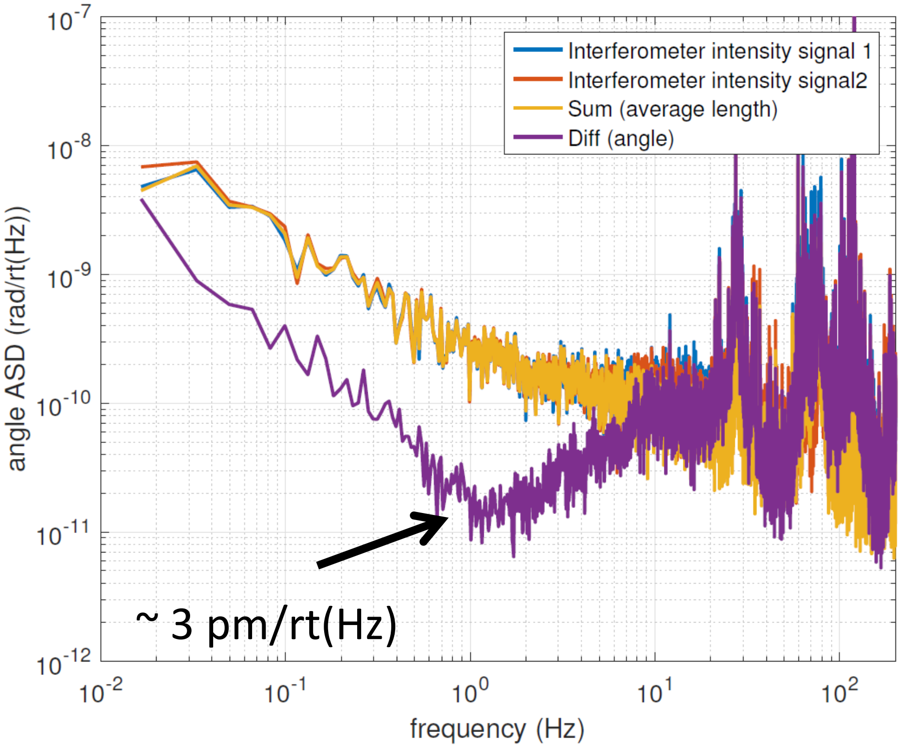
Schematic



Beam balance
Flexural spring
Mirror
Collimating lens
Beamsplitter-
coated fiber
Piezo - driven
translation stage
Rigid Support Structure
Splitter (1:2)
Circulator 1
Circulator
optic-fiber
IR diode laser
PD 1
PD 2

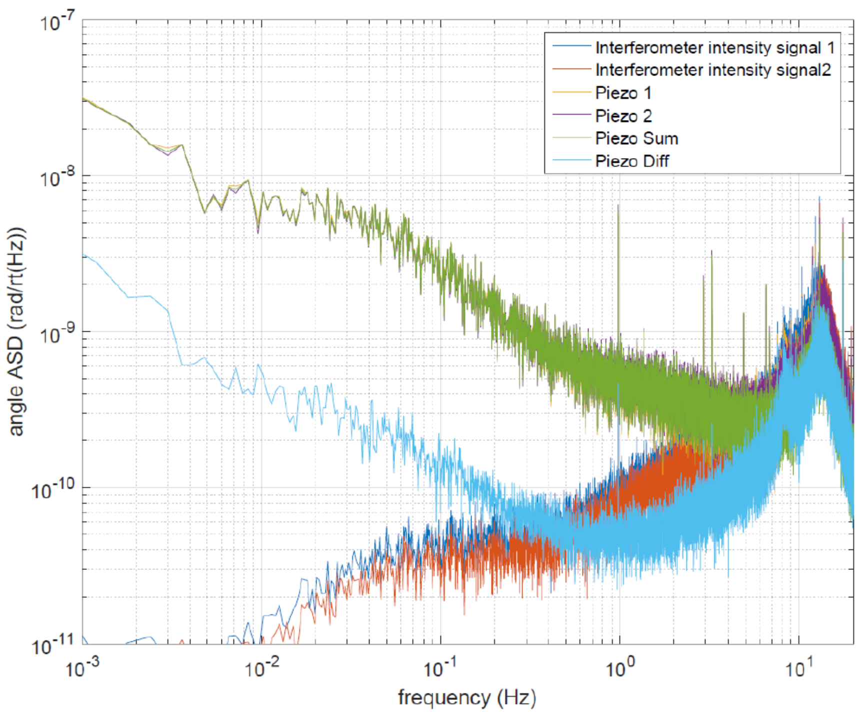
Readout sensitivity

Individual interferometer limited by frequency noise. Differential signal (angle channel) reduced frequency noise by matched cavities.



Readout with "soft control"
Piezo – stacks locked at ~ 5 mHz
Tilt signal is in the PhotoDiodes

Readout with "hard control"
Piezo – stacks locked at ~ 5 Hz
Tilt Signal is in the drive



Summary

1. BRS allows an unambiguous separation of tilt and horizontal acceleration between 0.01 to ~30 Hz.

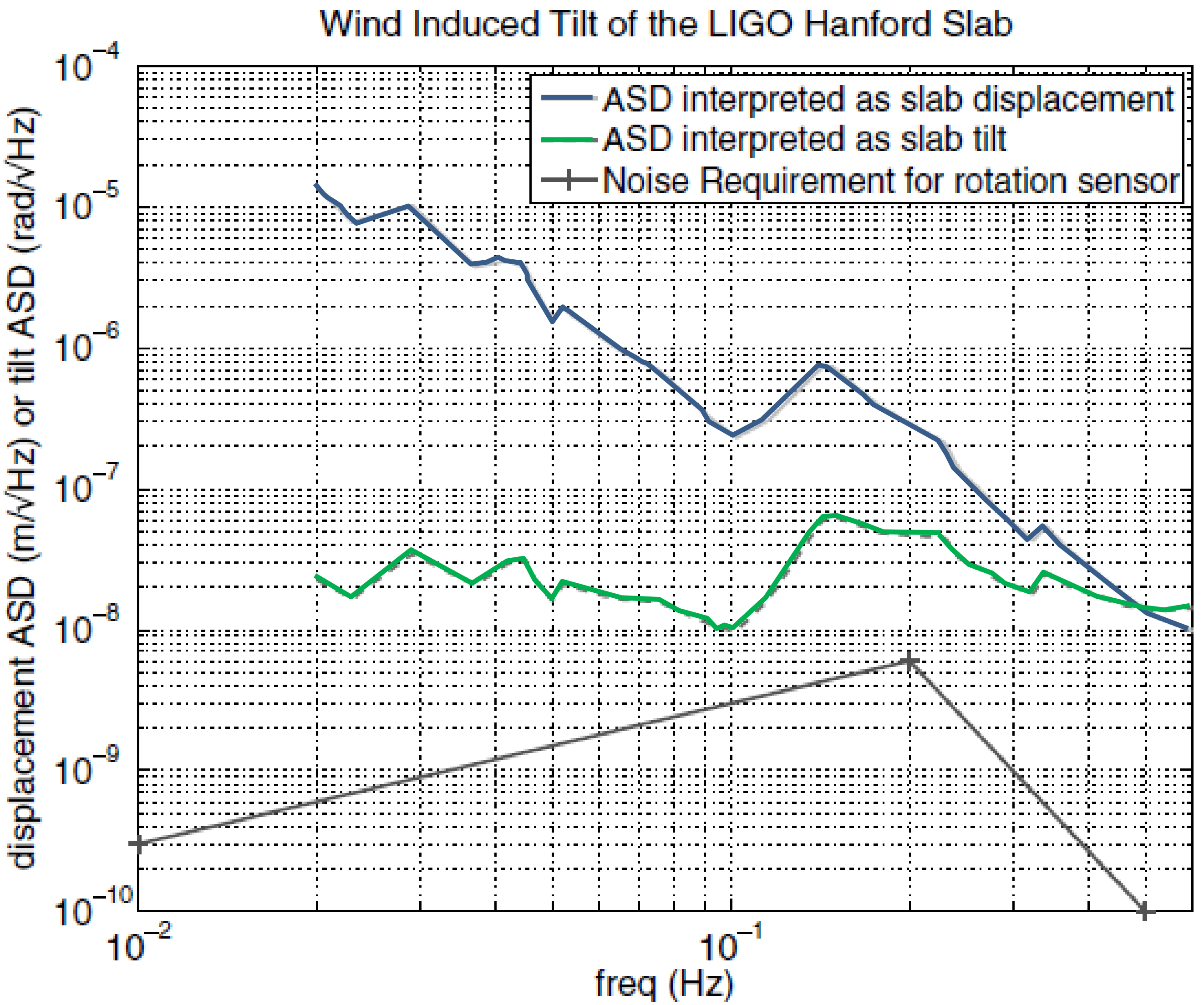
2. BRS-1 and BRS-2 can improve total RMS differential motion of the Optical Platforms in LIGO and improve isolation, especially under windy conditions.

3. A new compact prototype (cBRS) is under development. When placed on the Optical Platforms, it can significantly boost angular isolation. It may also prove useful in Newtonian Noise measurement at 10 Hz.

Thank you!

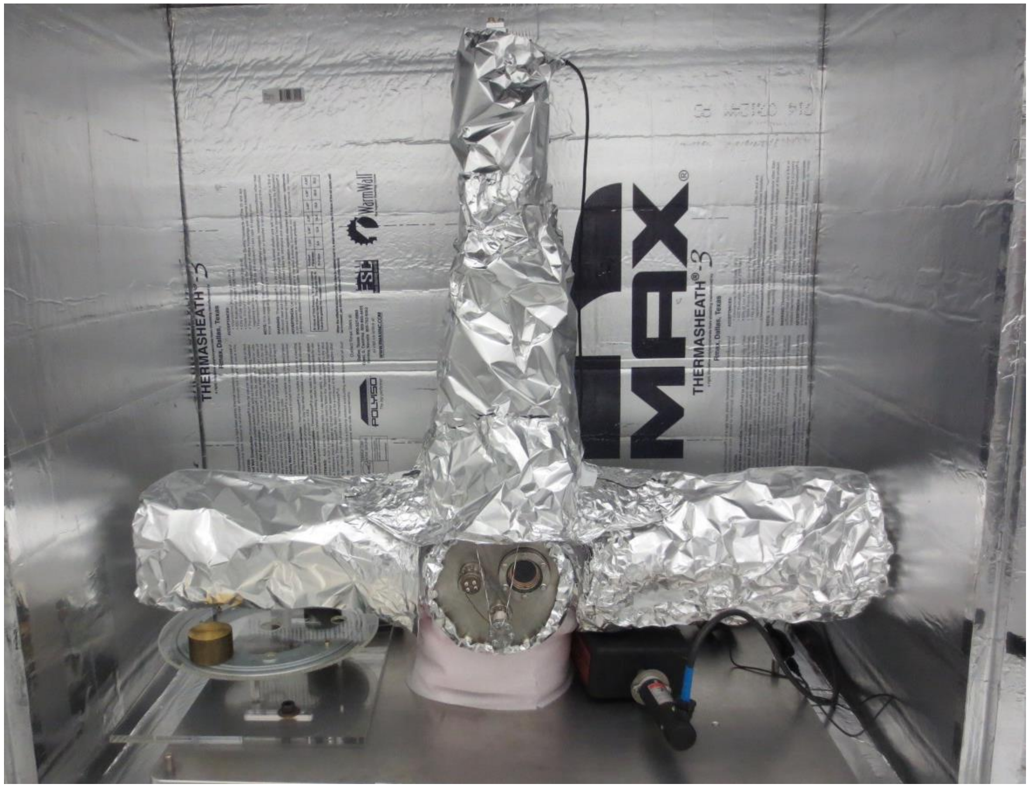
Extra slides

Target sensitivity

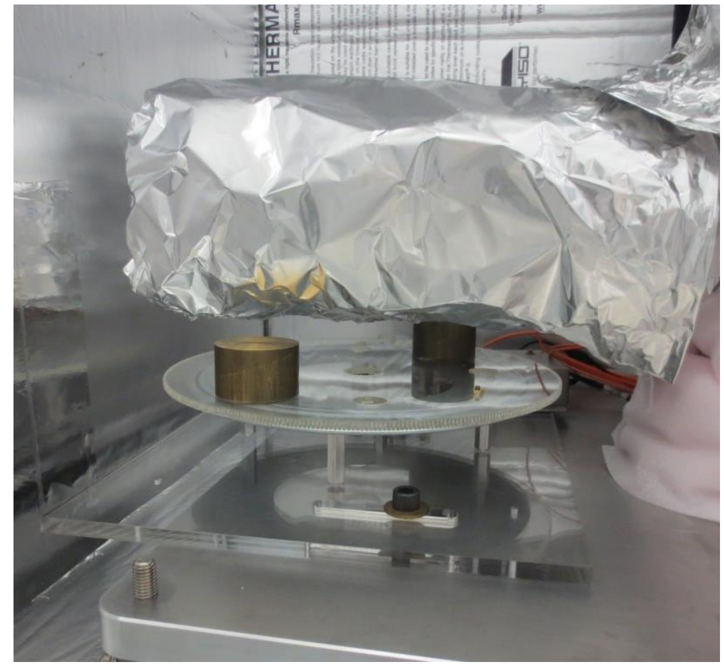


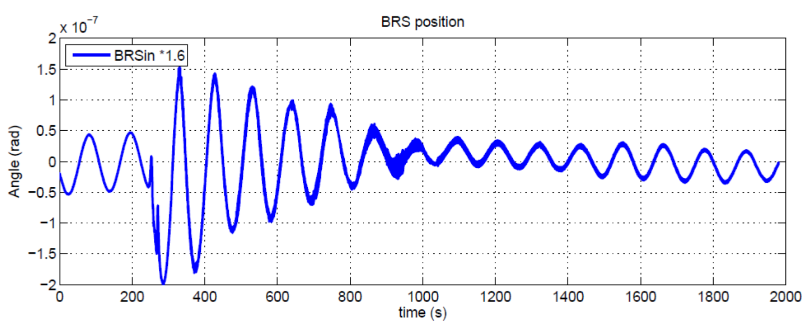
from *"Requirements for a ground rotation sensor to improve Advanced LIGO"* (B. Lantz *et al.*, 2009)

Damper Installation



gravitational feedback system!

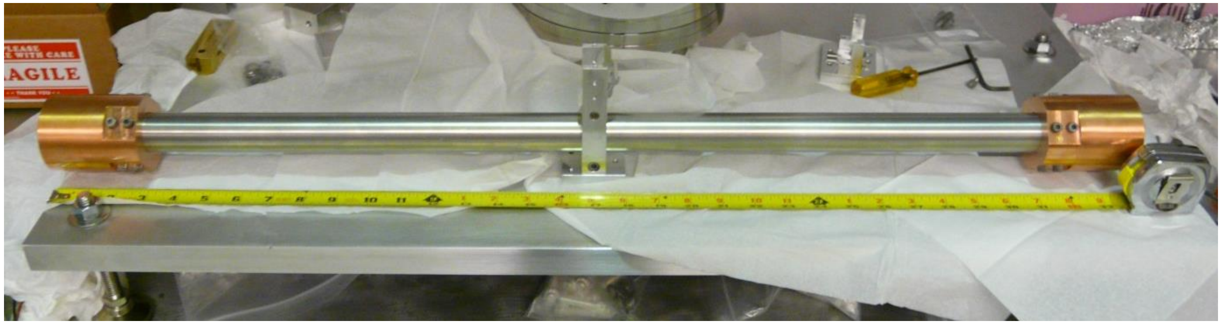




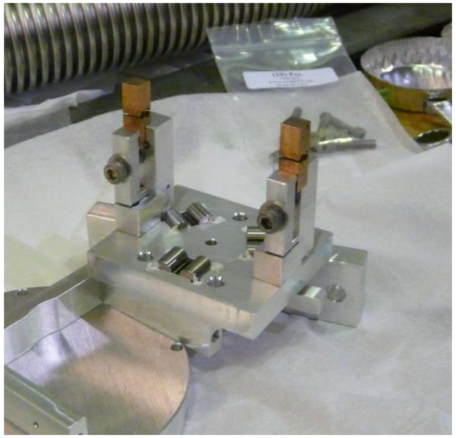
A turn-table applies a gravitational torque on the balance to actively damp the beam-balance when amplitude exceeds a threshold.

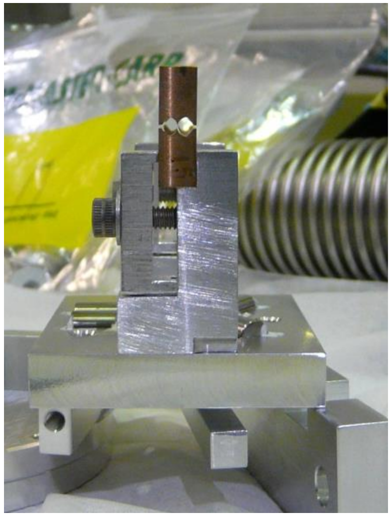
Ref: LHO 14388

BRS-2 Assembly pictures



Assembled beam and weights

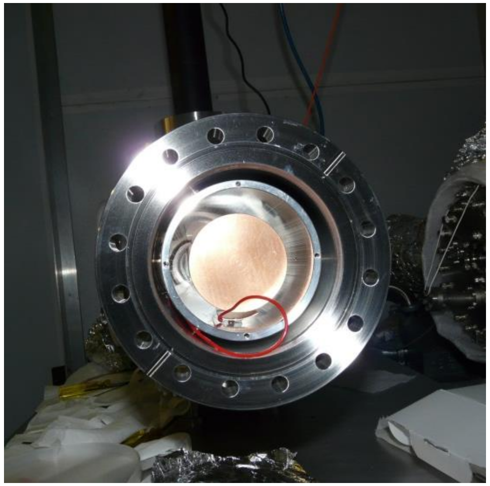




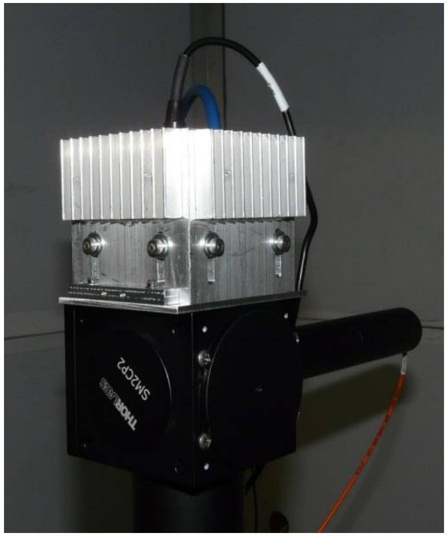
Flexures

Integrated with vacuum chamber

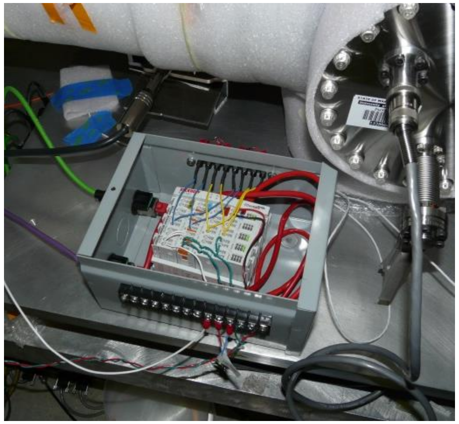
BRS-2 Assembly pictures



Capacitor plates



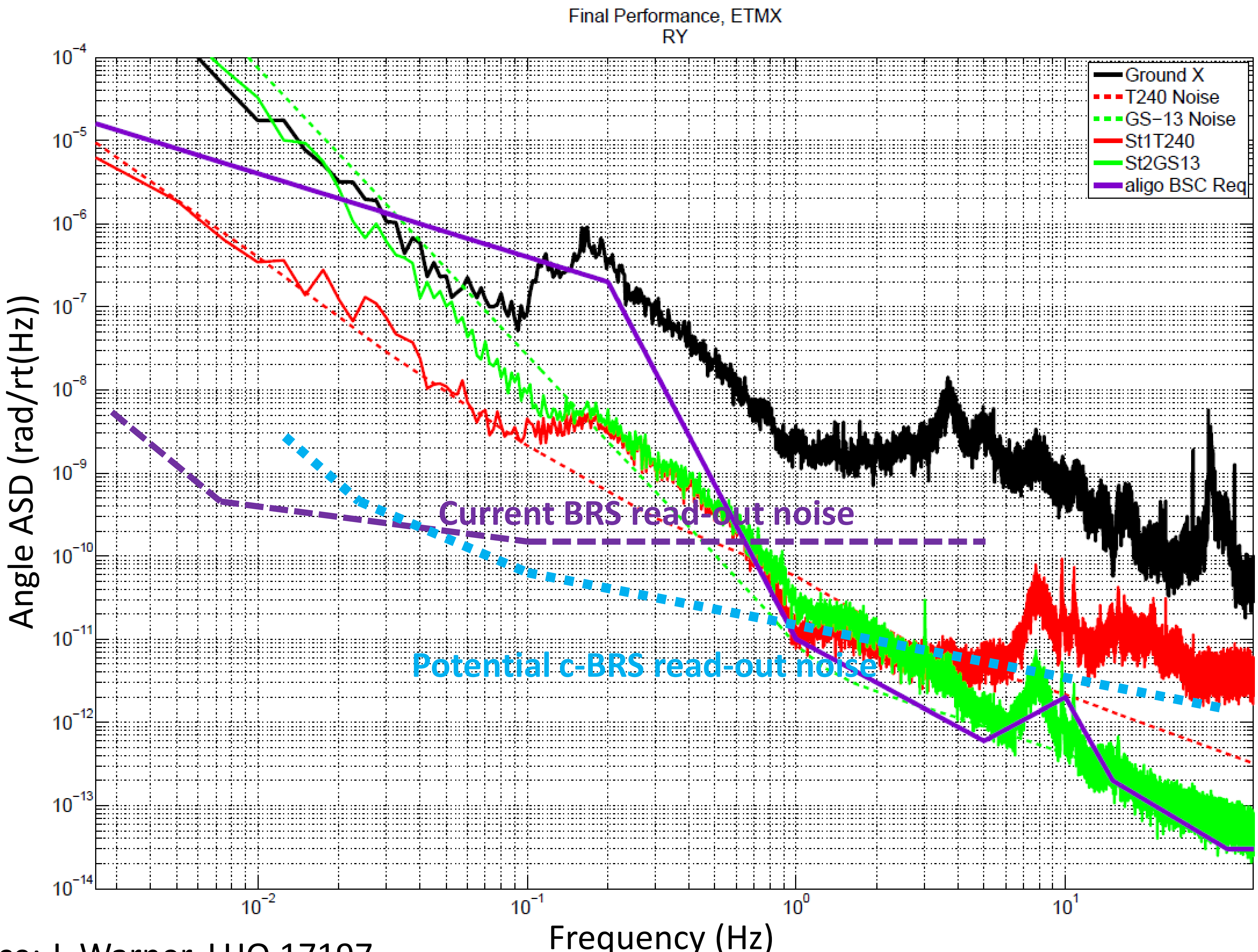
Basler CCD camera



Beckhoff modules

Foam box

Sensitivity comparison



Source: J. Warner, LHO 17197

cBRS Tilt data