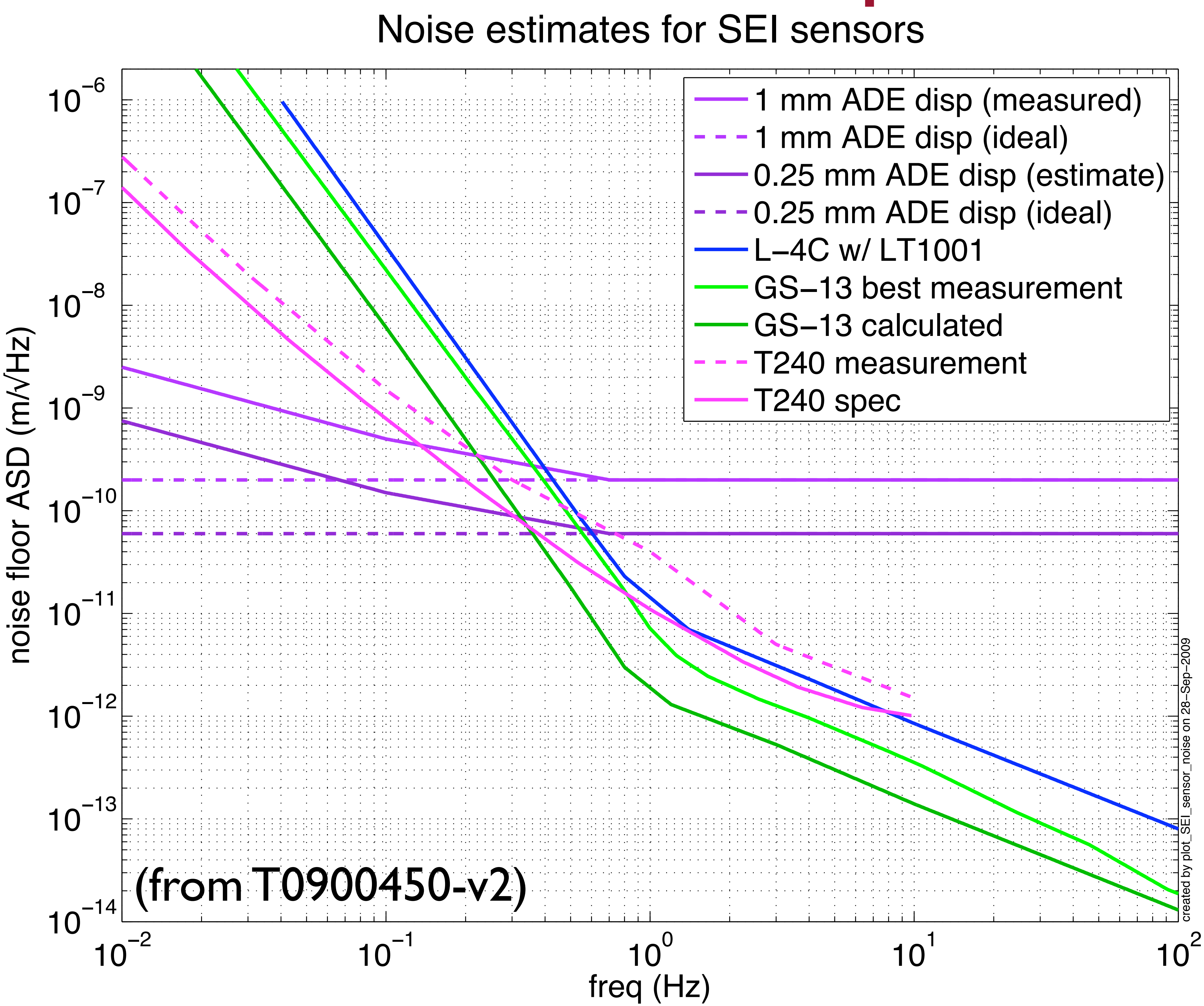
BSC-ISI electronics
Review of the
sensor noise and range

Brian Lantz, Ben Abbott March 30, 2010

Analog readouts for BSC-ISI

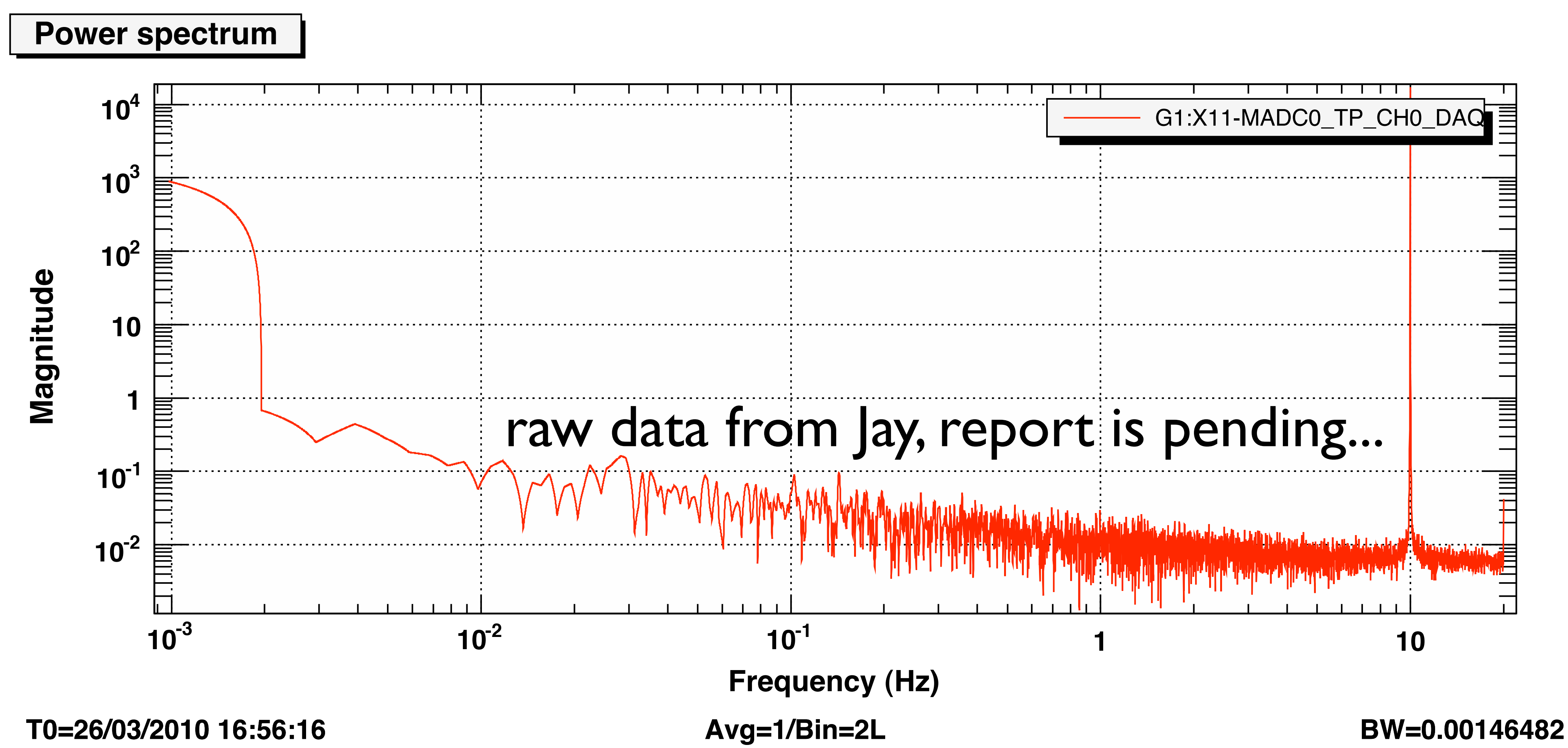
- 3-fold goal for readout electronics filtering
  1. Enough range for commissioning.
  2. Enough range to ‘almost never’ saturate in operation.
  3. The ADC noise does not limit stage performance.
     (limited by either inherent sensor noise or loop gain of stage)
  4. Note: I have unilaterally updated the BSC reqs at 10 Hz - not accepted, but it doesn’t matter for these plots.
- Use several inputs to the calculations
  1. Noise - Sensor noise estimates from Stanford (T0900450)
  2. Noise - Noise measurements of ADC boards by Jay
     with some recent measurements by Jeff K on HAM6-ISI
  3. Range - HAM6-ISI readouts for the GS-13s.
     (damping off for early commissioning, damping on for running)
  4. Range - LASTI readouts for the stage 1 STS-2s.

Sensor Noise Inputs



ADC noise

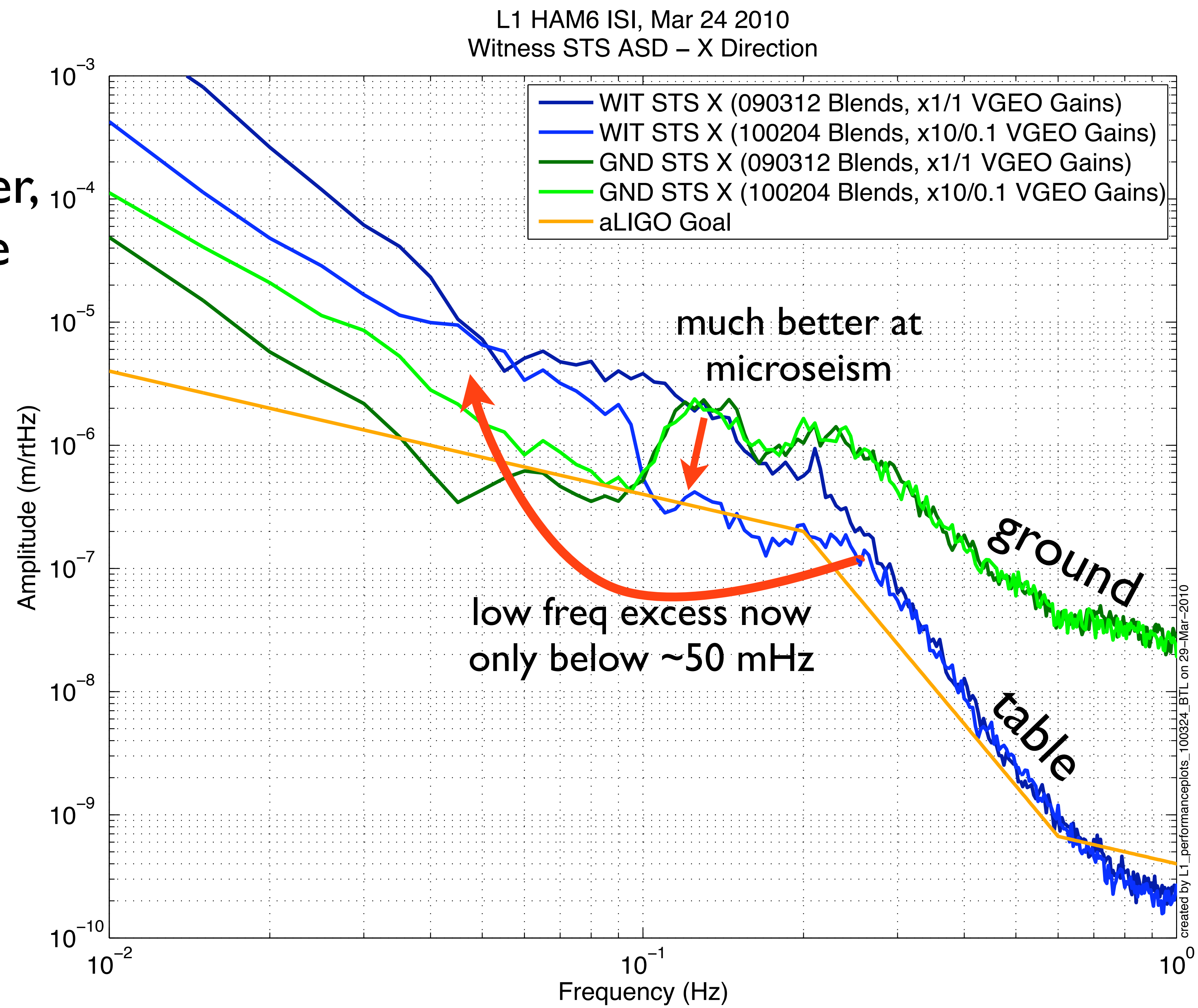
- Originally believed 4e-6 V/√Hz, flat.
- New data from Jay H. last week shows
  - 6e-6 V/√Hz at 1 Hz, 60e-6 V/√Hz at 0.01 Hz, 4e-6 near 10 Hz
  - Worse than value used for original designs.
- Jeff K demonstrated better GS-13 low-freq performance using x10 analog gain before the ADC (last week)



Noise improvement on HAM6-ISI

Implemented x10 additional analog gain before the ADC, saw 2 interesting things...

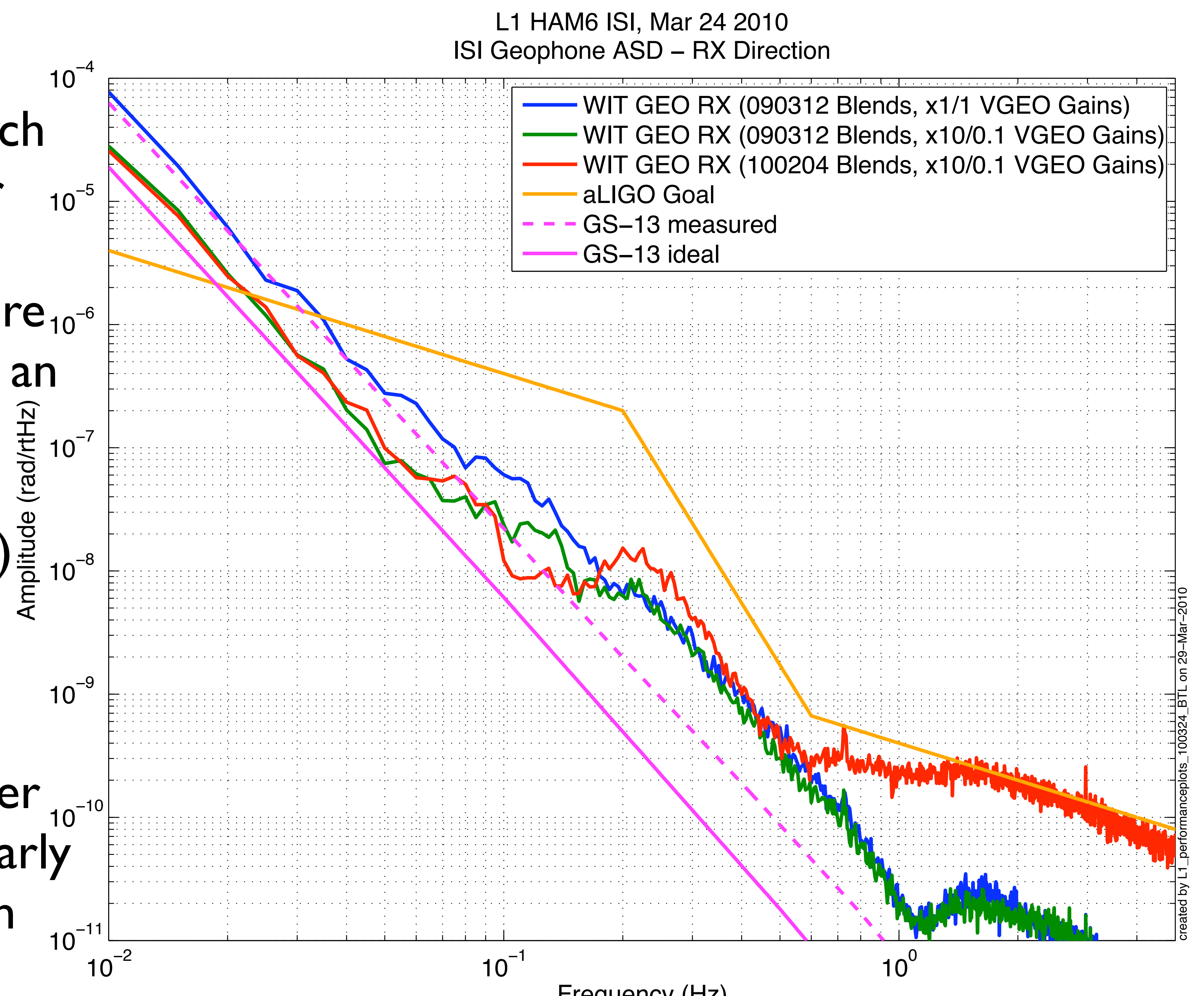
First:
X performance much better, matches expectation above ~50 mHz (was ~250 mHz)
- BECAUSE -
low freq excess tilt is dramatically reduced.



Noise improvement on HAM6-ISI

Implemented x10 additional analog gain before the ADC, saw 2 interesting things...

Second:
GS-13 noise now seems much closer to expected amplifier noise.
Plot the RX signal as if it were the noise contribution from an individual sensor (invert the projection matrix, assume equal noise from all sensors)
Old noise (blue) matches 'best measured'
-BUT-
New noise (green, red) better than 'best measured' and nearly matched amplifier prediction



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Range for Inputs

- GS-13s in 'Low Gain' on stage 1 of HAM6-ISI almost never saturate in operation. Should be fine for Stage 2 of BSC-ISI for Commissioning.
  - OK for blasting (C. Gray, LLO ilog, April 21, 2009)
  - OK for Hurricane Ida Landfall (J. Kissel in LLO ilog, Nov 10, 2009)
  - Sometimes saturates on Tip-tilt shutter impacts (when the mirror hits the cage)
- GS-13 Channel low-gain (sensor * readout chain) about 1.8e5 V/(m/s)
- High gain (*10 larger) makes commissioning difficult, but allows us to improve low frequency performance limit from ADCs. High gain will be needed for high-performance operation.
- At LASTI STS-2 on Stage 1 usually OK, so this level should be OK at observatories. Channel gain is 1.3e5 V/(m/s). Originally set at (100/42) bigger = 3.1e5 V/(m/s) which caused saturations.
- Assert: OK at LASTI = OK at Observatory, or if integrated RMS small (< 1V 'typical' for 40 Vp-p ADC) then OK.

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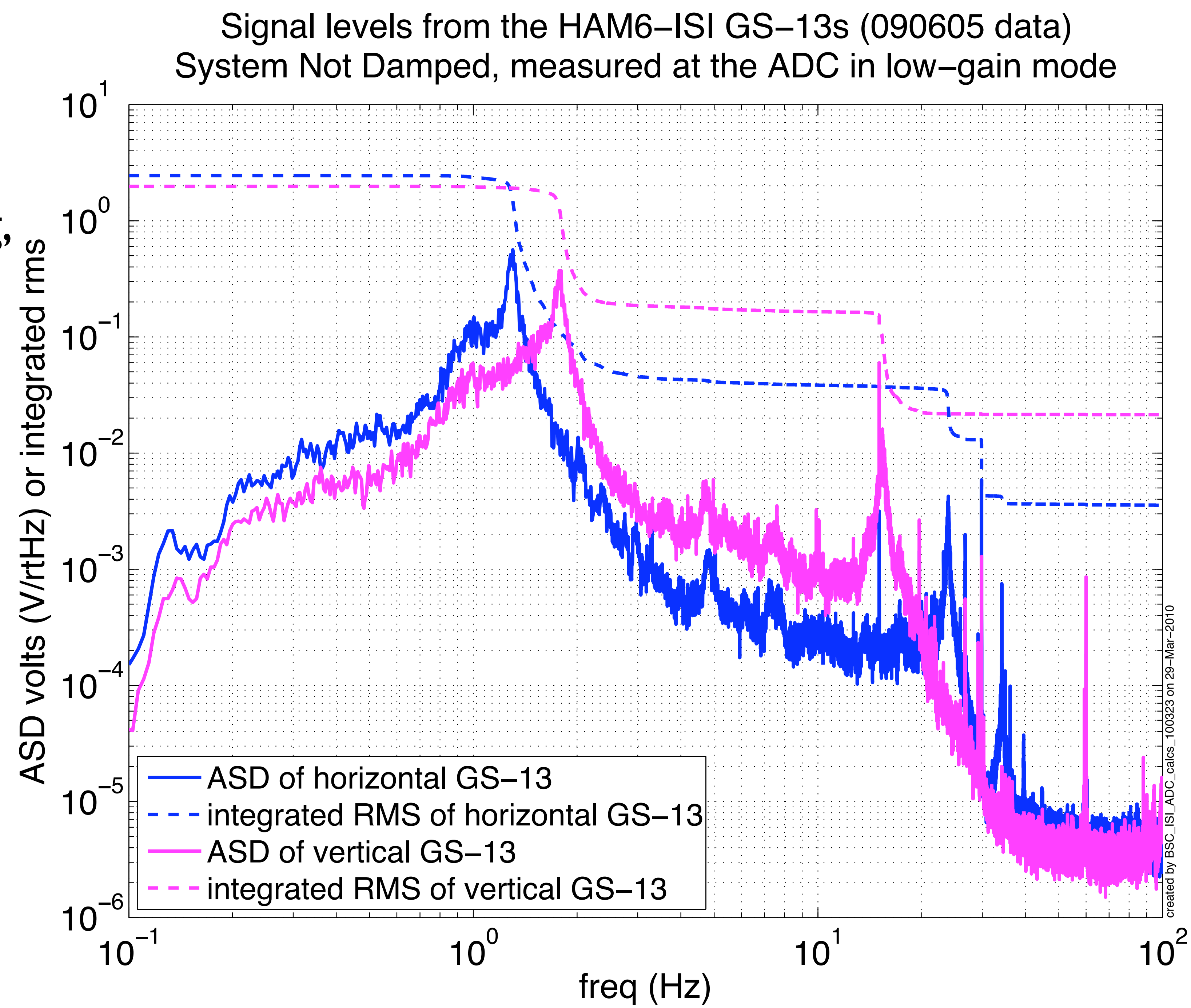
Range reference

This level of rms allows commissioning, but is not robust (GS-13s on stage 1 of HAM6-ISI, no damping)

measured data from HAM6 on June 5 2009 * HAM 6 analog readout at that time

'typical' 2 V rms at ADC
(for 40 V p-p range)
is OK for commissioning,
we have done this.

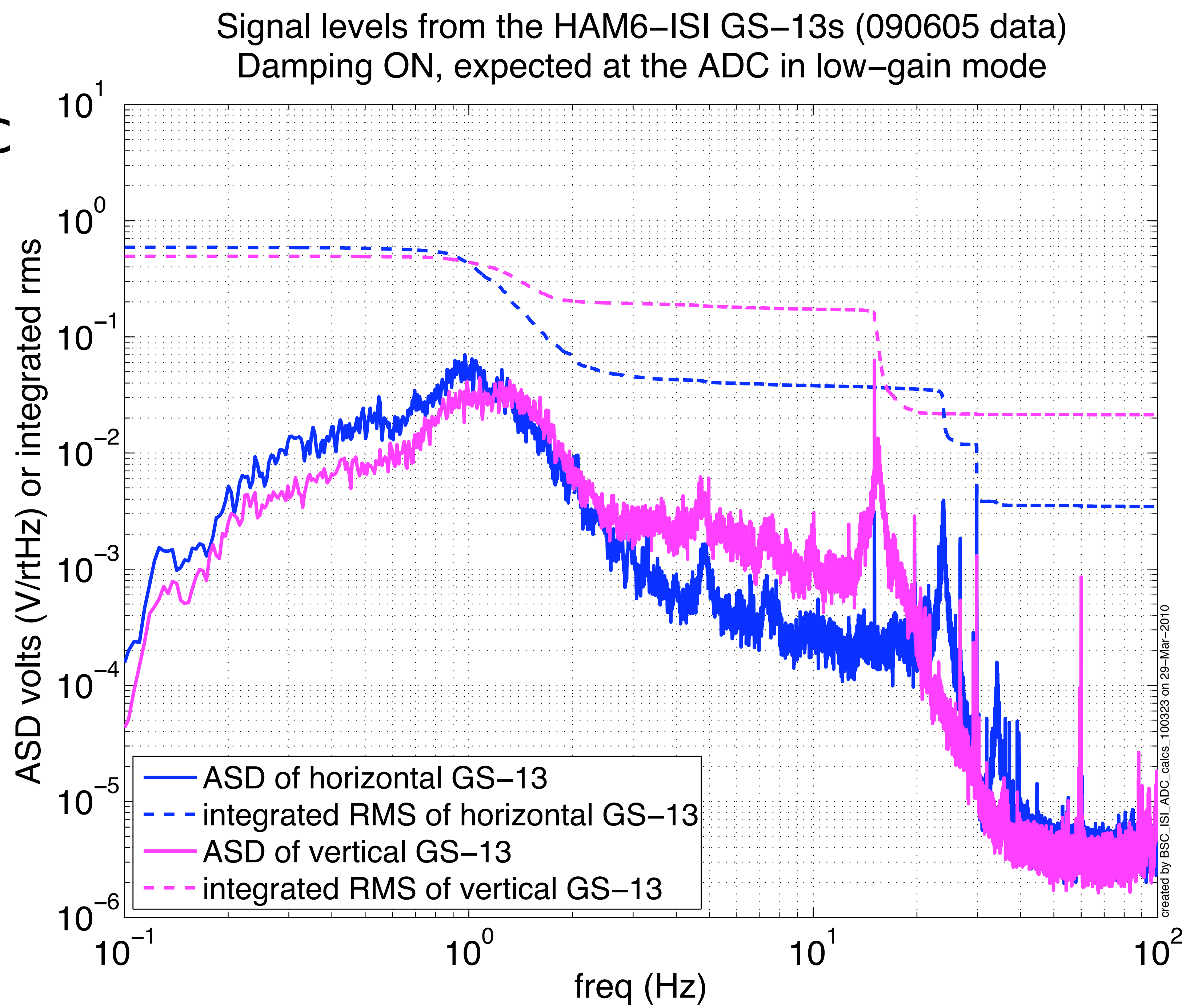


Range reference

This level of rms is quite robust (GS-13s on stage 1 of HAM6-ISI, damping ON)

measured data from HAM6 on June 5 2009 * HAM 6 analog readout at that time

'typical' 0.5 V rms at ADC (for 40 V p-p range) is quite robust



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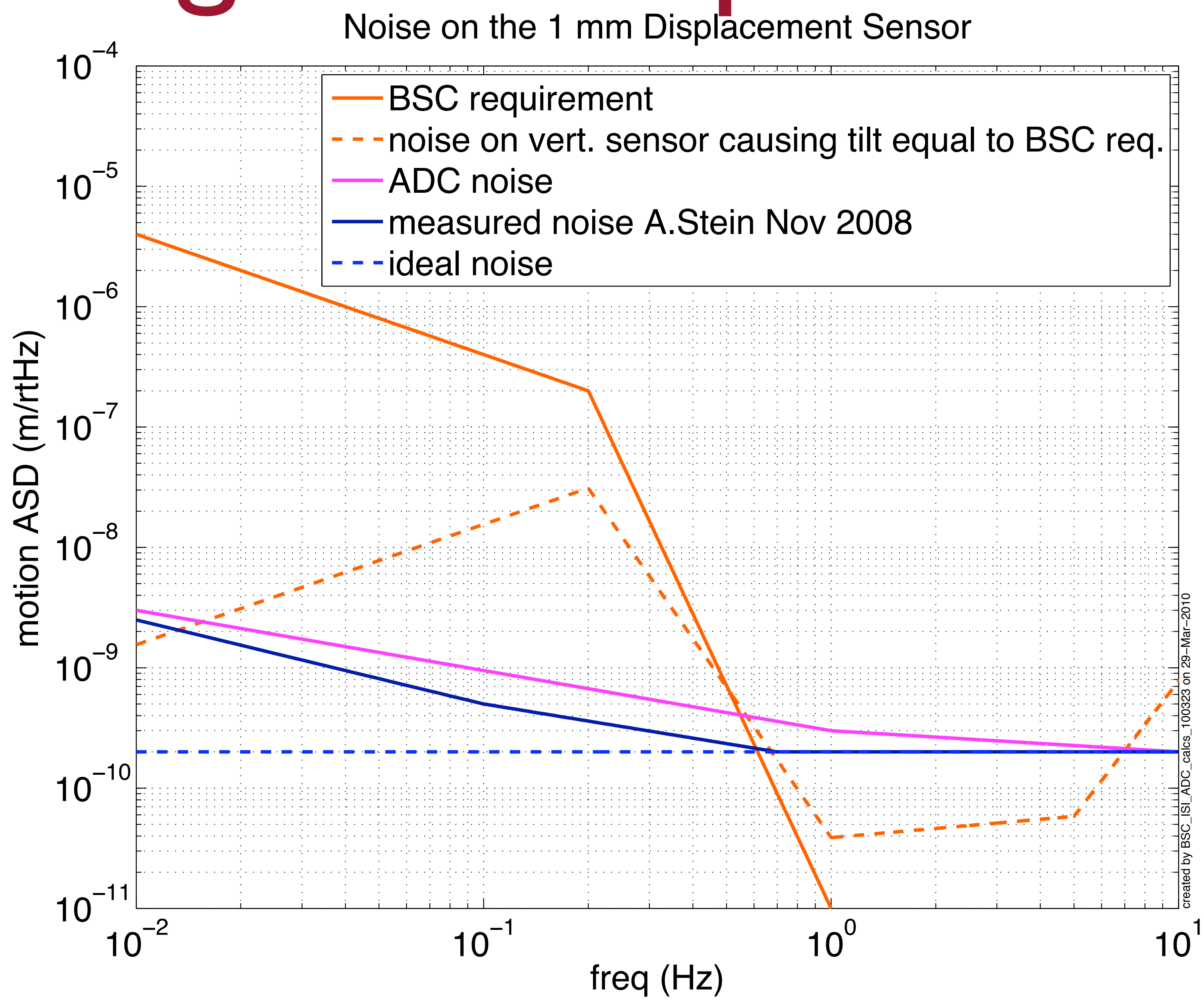
So far...

- Set expectations for
  - sensor noise,
  - ADC noise,
  - showed impact of this on HAM6-ISI,
  - acceptable voltages at the ADCs.
- Next, for sensors on BSC, show filters which achieve this (or get close).

Displacement sensor

- stage 0-1 is 20V differential for 1 mm
  - not using any additional gain at low frequency, need full range.
  - low frequency noise of ADC means we can not hit ideal sensitivity of the displacement sensor.
  - Does not strongly impact the requirements. Does cause irritation and reduces flexibility of blend filters.
  - Could be helped a bit with a bit more whitening gain between 100 and 400 mHz. Ben has a design for this.
- stage 1-2 is 20V differential for 0.25 mm.
  - noise and range scale exactly together.
  - Only plotting stage 0-1.

Stage 0-1 displacement sensor



1. Measured noise at low freq is from thermal drift of test rig.
2. Measured noise at Hanford not quite this good (see 5e-10 m/rtHz)
3. ADC will be a real limit to the sensor noise below either a few Hz, or below 300 mHz (if LHO measurements hold).
4. Noise sets blend freq to be below ~300 mHz (not a big problem, need space to roll off gain).
5. Below 15 mHz, the table will have some extra tilt. This will **not** cause **real** translation, (too far below blend freq) but a witness T-240 **will appear** to show excess translation.

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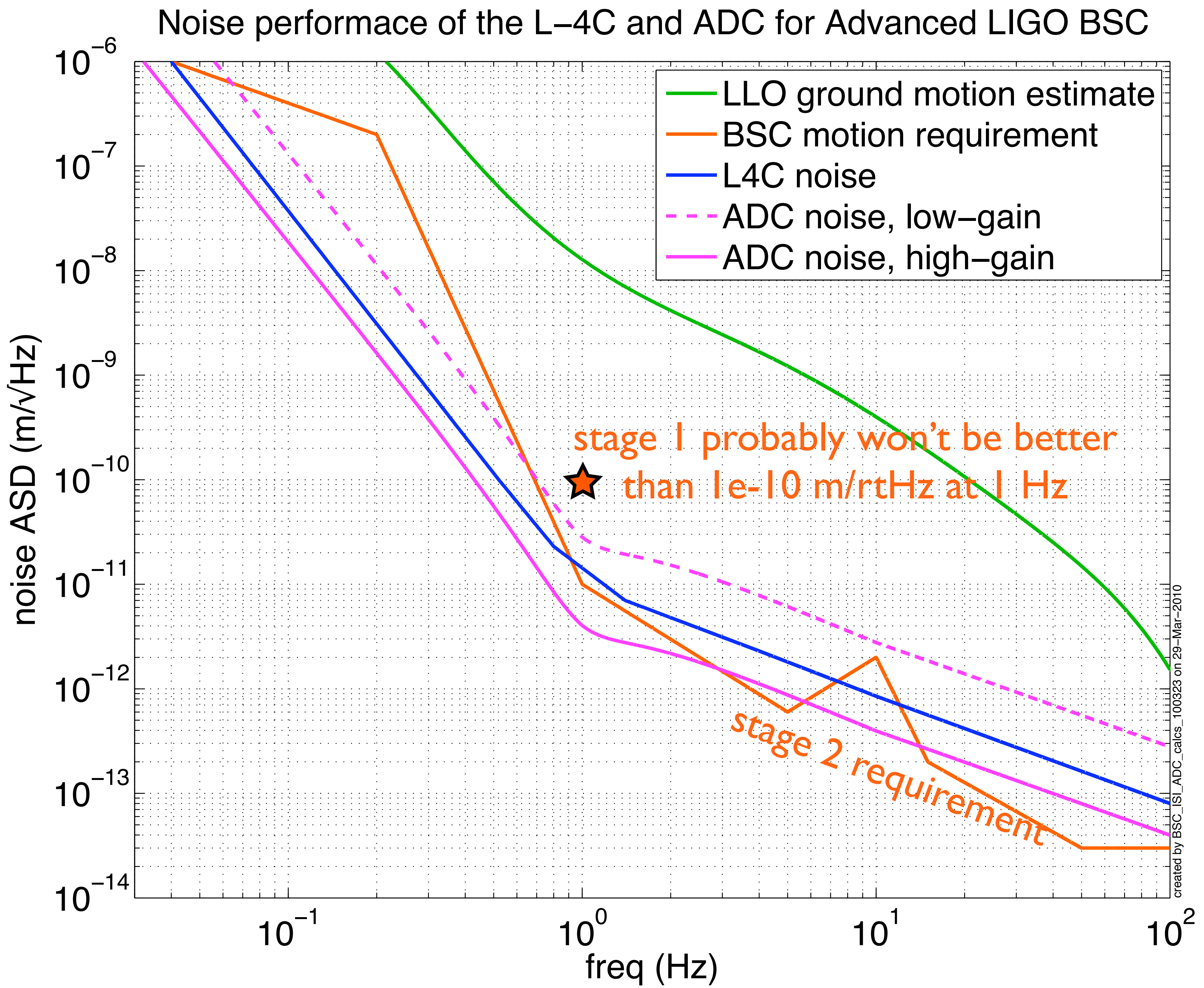
L-4Cs for stage 0 and stage 1

- preamp gain of 44 V(differential) per volt from L-4C
  - twice the gain of the preamps at LASTI
  - make signals in cables bigger.
- switchable ISI-readout gain of
  - low-gain = 2 (input of 1, output gain stage of 2)
  - high-gain = 14 (input of 7, output gain stage of 2)
- stage 0 Feedforward always in low-gain.
- stage 1 commissioned in low-gain, switch to high-gain
- use same electronics for both sets.

L-4Cs for stage 0 and stage 1

ADC noise - as displacement

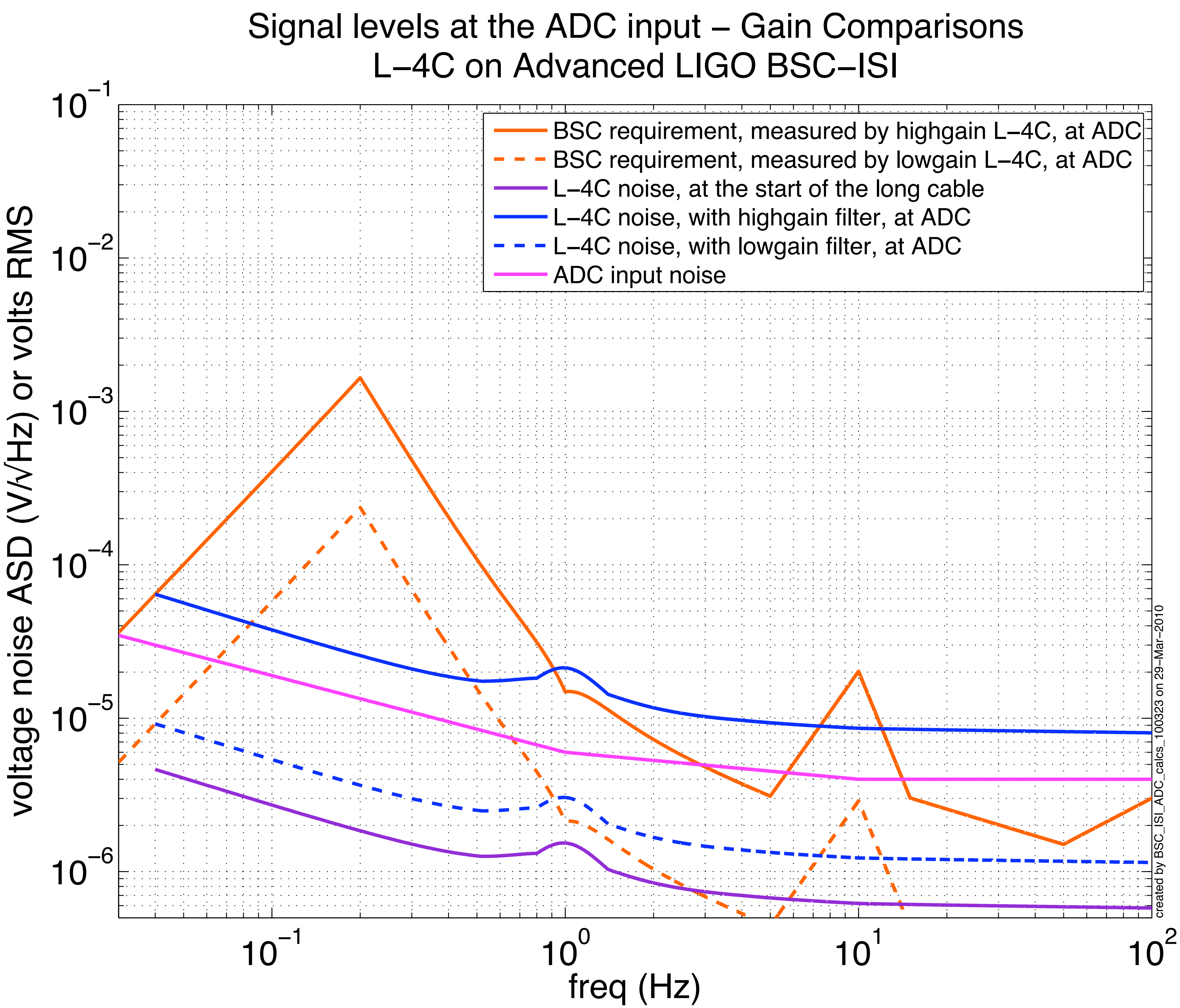
Low gain mode
good enough to clearly resolve ground motion and stage 1 motion from 1 to 10 Hz,
High gain mode,
ADC noise is 2x below sensor noise above 1 Hz



L-4Cs for stage 0 and stage 1

ADC noise - at the ADC input

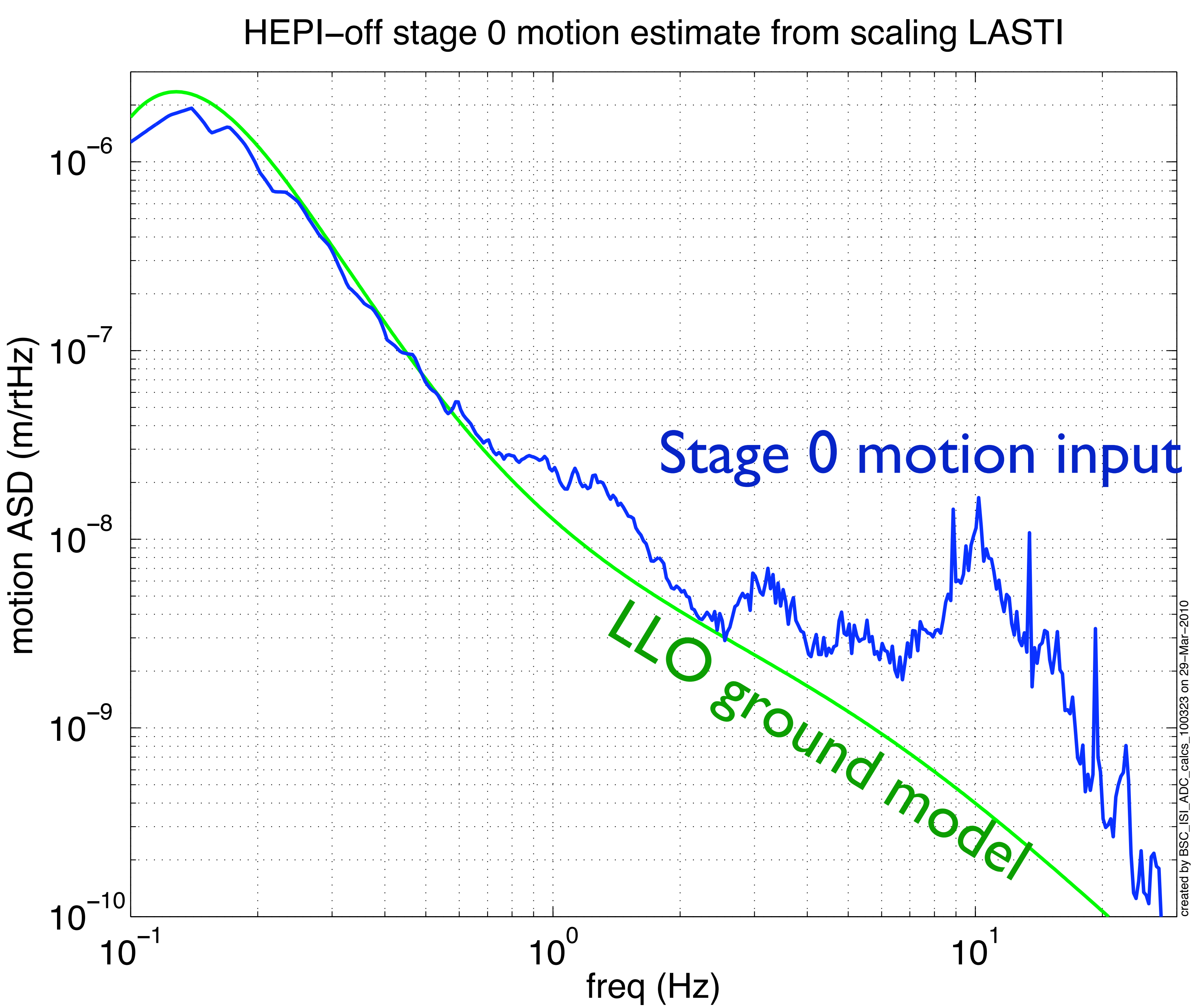
Low gain mode
good enough to clearly resolve ground motion and stage 1 motion from 1 to 10 Hz,
High gain mode,
ADC noise is 2x below sensor noise above 1 Hz



L-4Cs for stage 0 and stage 1

Range for Stage 0

stage 0 motion estimate is LASTI HEPI X with HEPI off
scaled by ratio of old LLO ground X to LASTI ground X
5x more motion at 10 Hz than Barsotti & Waldman estimates



L-4Cs for stage 0 and stage 1

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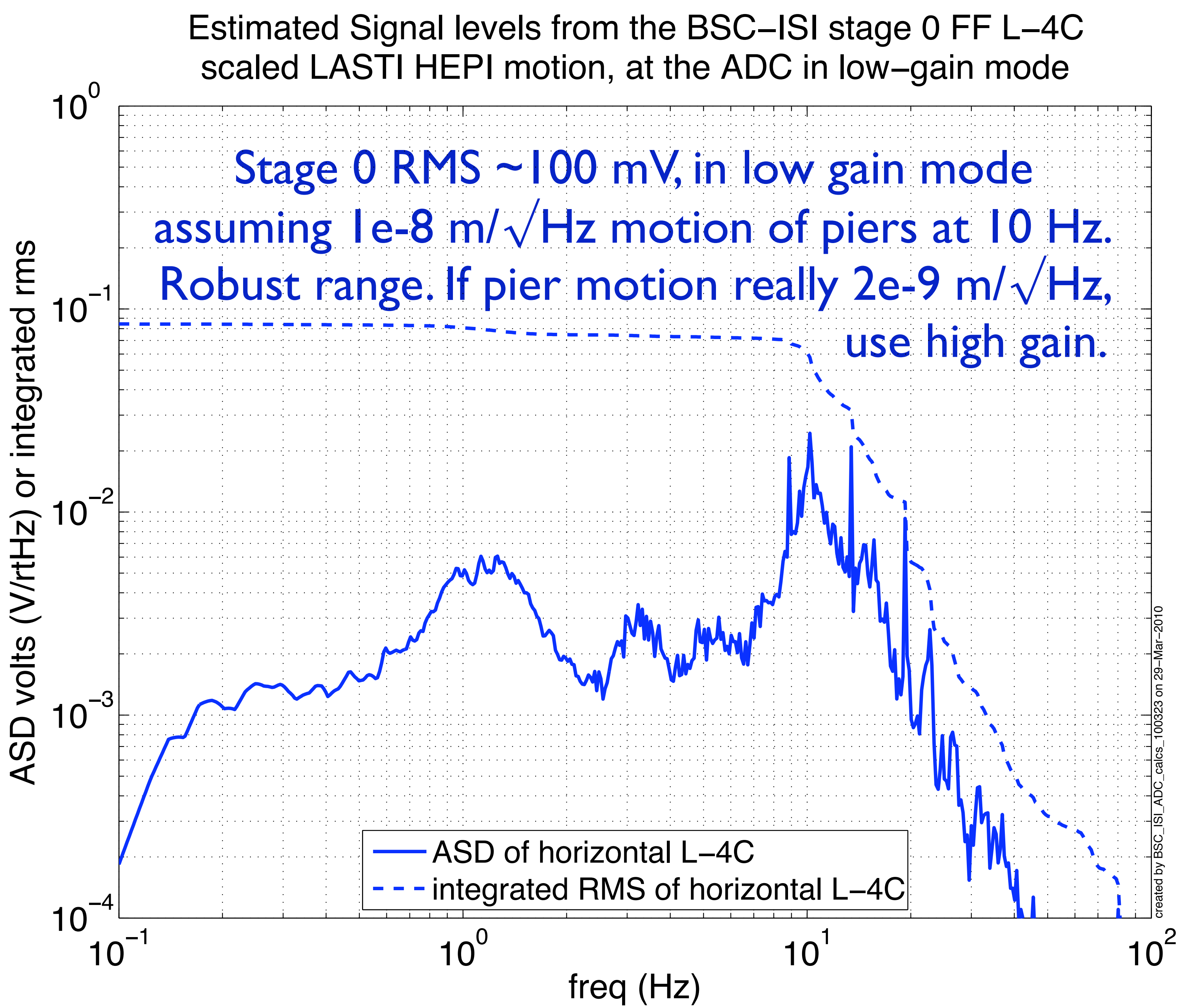
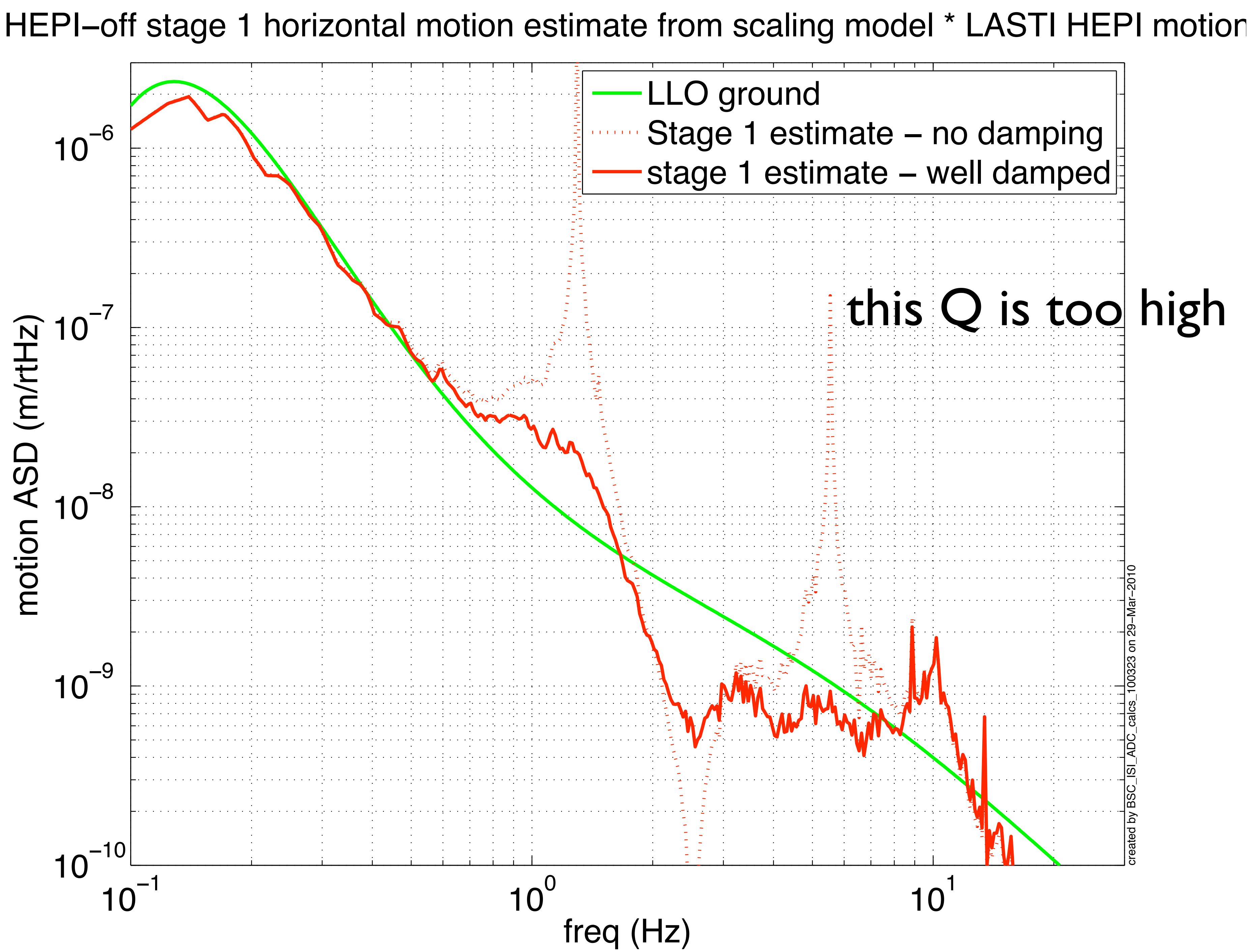


L-4Cs for stage 0 and stage 1

Range for Stage 1

Use HEPI X estimate (previous) * plant model with or w/o damping.



L-4Cs for stage 0 and stage 1

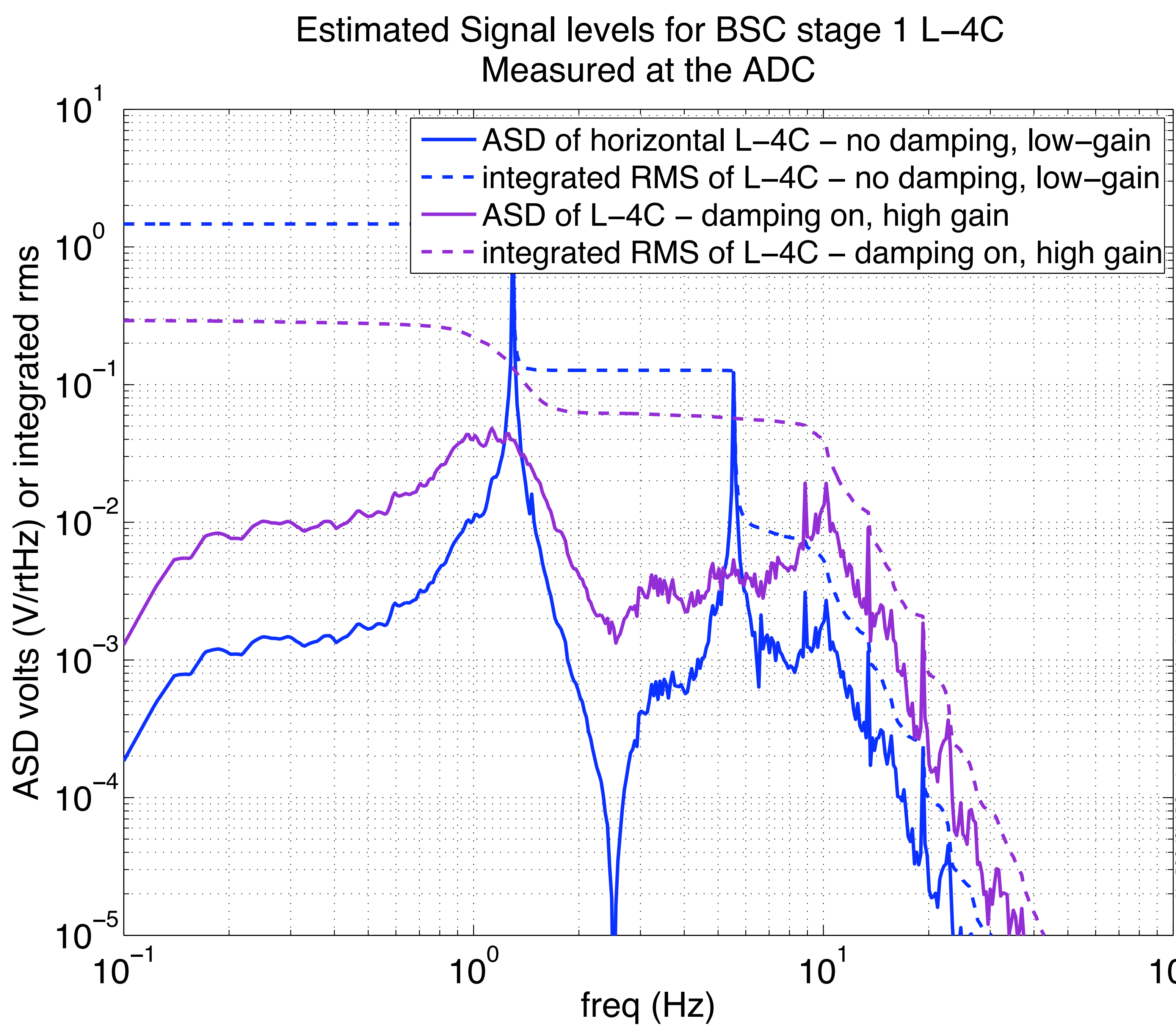
Range for Stage 1

Use HEPI X estimate (previous) * plant model with or w/o damping.

Can commission with low-gain and damping off

Run robustly with high-gain once damping is on

Conclusion:
When commissioning, first thing to do is turn on the stage 1 damping.



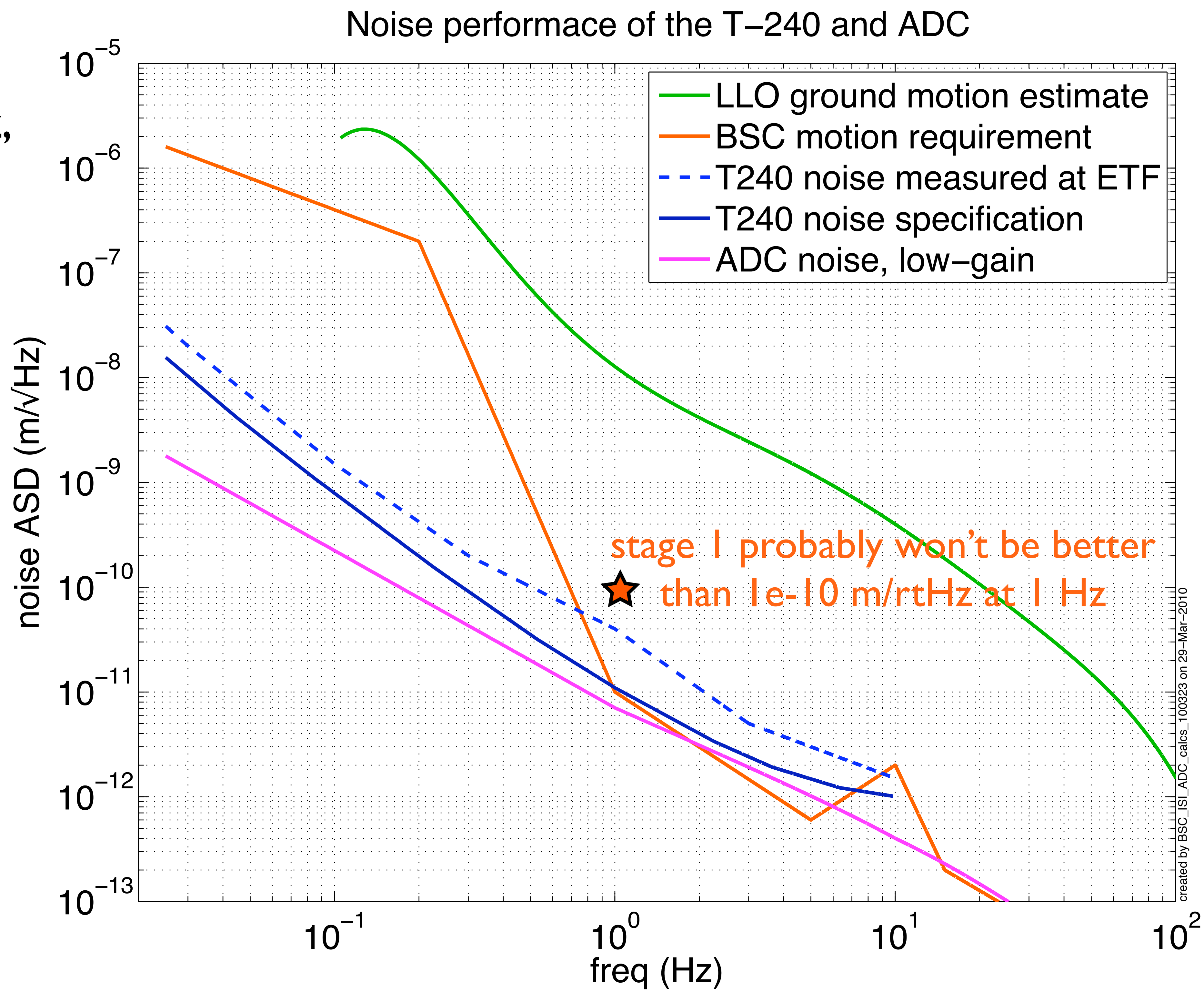
T-240 for stage 1

- internal differential driver with gain of 1196 V/(m/s) at 1 Hz
- fixed gain readout of 113 V/V (and AA gain of 1 at DC)
  - readout gain is 1.35e5 V/(m/s)
  - gives ~same total readout gain as now in use at LASTI
  - 1500 V/(m/s) of STS-2 * readout gain of 42 * antialias gain of 2.1
  - Low gain of HAM6-ISI GS-13 is 1.8e5 V/(m/s) above a few Hz.

T-240 for stage 1

ADC noise - as displacement

ADC noise is close to instrument noise at 1 Hz, but well below stage motion, and L-4C is also in use above 1 Hz.



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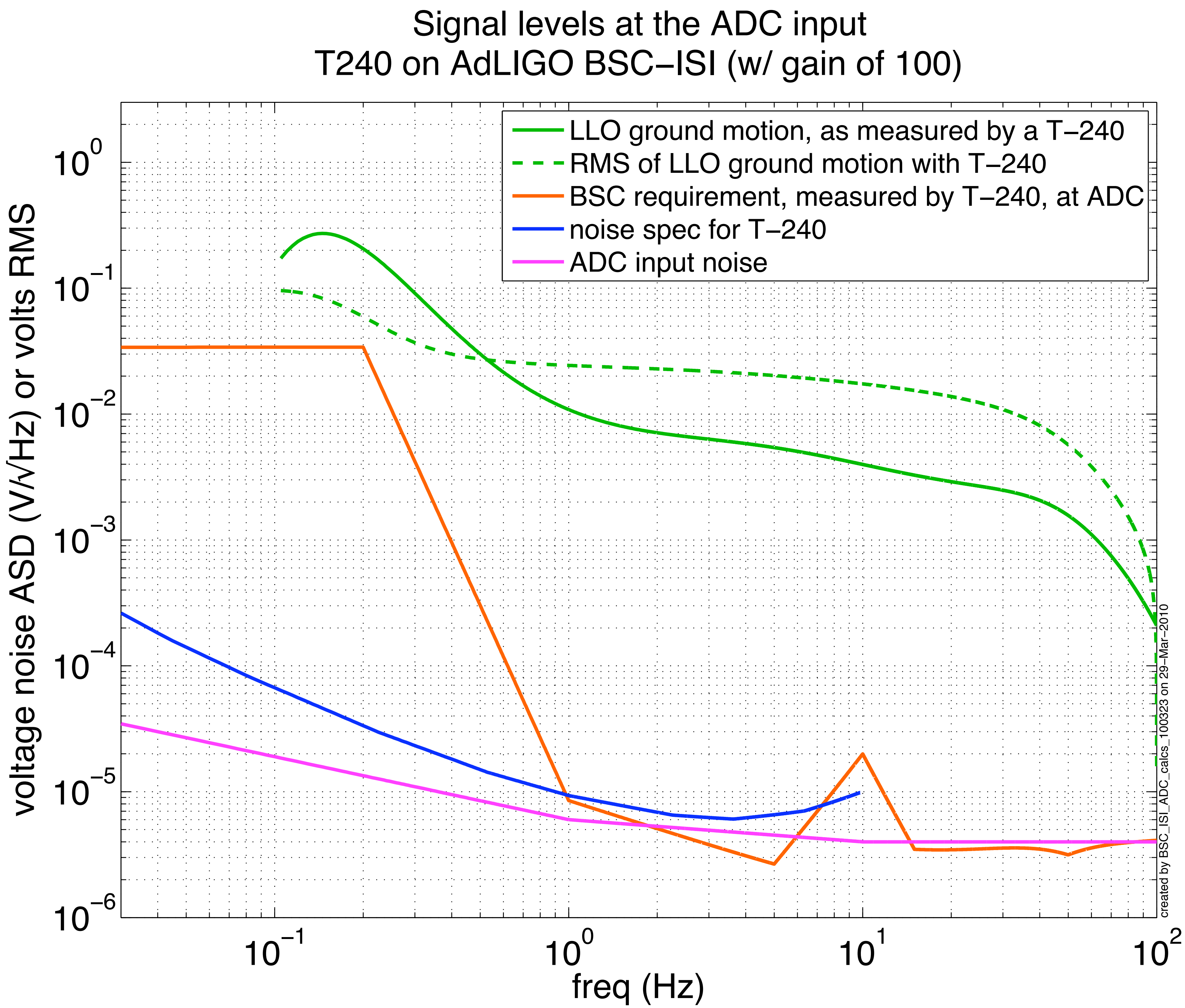
T-240 for stage 1

ADC noise - at the ADC

ADC noise is close to instrument noise at 1 Hz, but well below stage motion, and L-4C is also in use above 1 Hz.



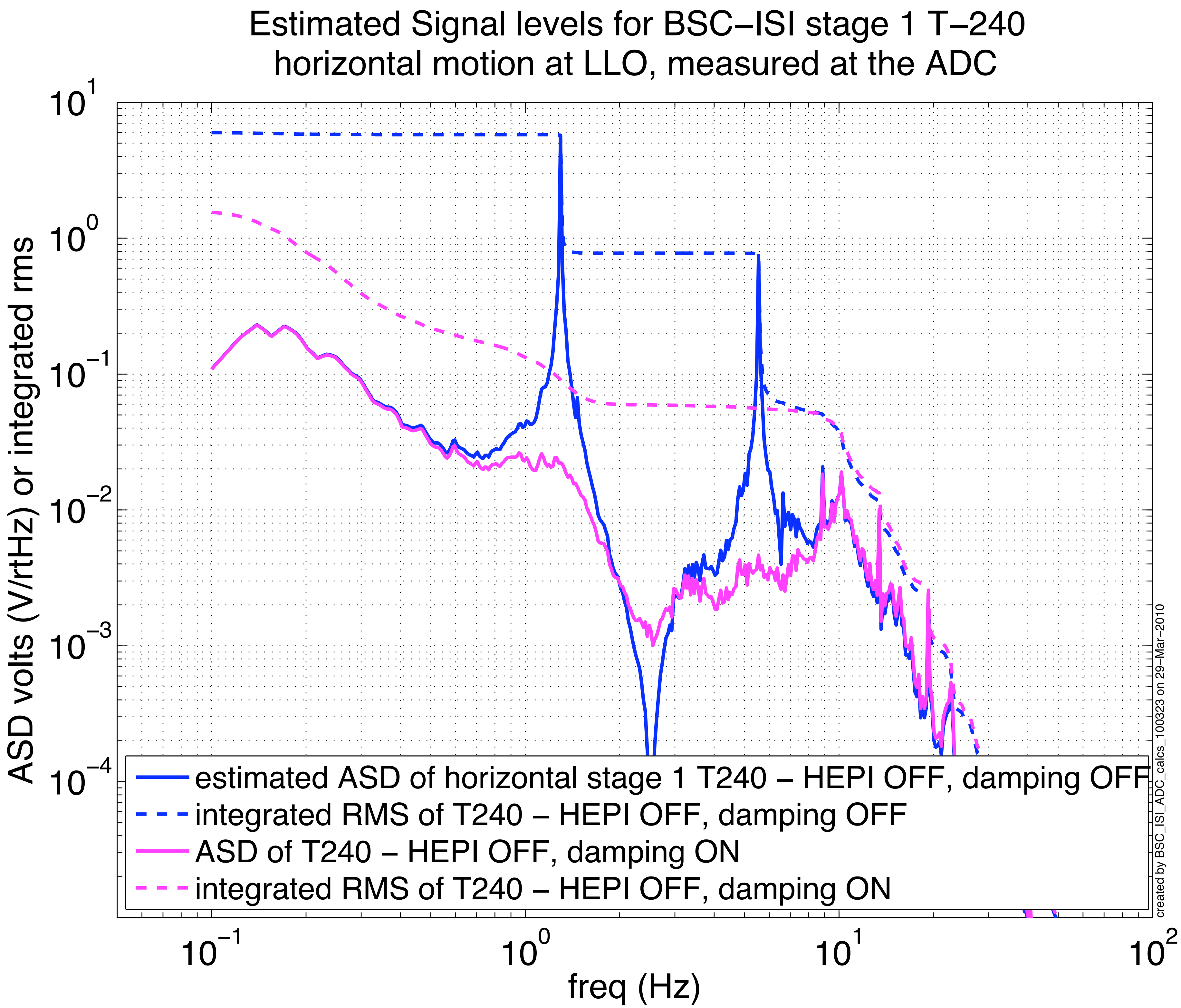
T-240 for stage 1

range estimate - HEPI off, stage 1 either free or damped

Range is tight without damping.

Probably need to get stage 1 damped before doing much with T-240s. Low frequency motion is majority of RMS

More gain probably not a good idea. Mostly helps at frequencies where we use L-4C, likely to impact the robustness.



GS-13 for Stage 2

- Internal differential preamp with gain of 40.2
- ISI readout box has switchable gain
  - Low-gain is DC gain of 2, with zero at 10, pole at 50 Hz
    good range, pretty good noise at high frequencies.
  - High-gain is fixed gain of 12 (input stage gain of 6).
    puts instrument noise least 2x below ADC noise at all frequencies.

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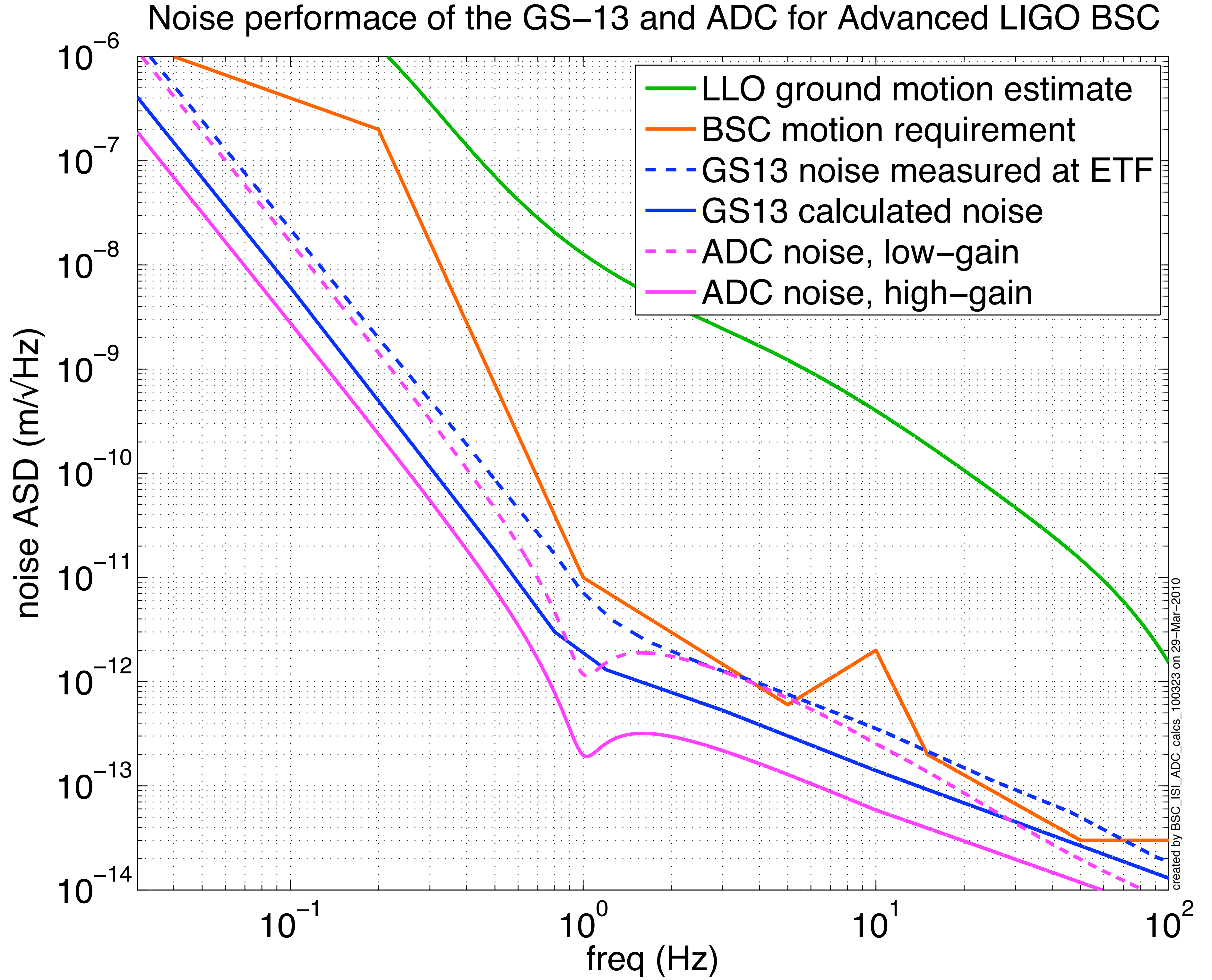
GS-13 for Stage 2

ADC noise - as displacement

Low gain mode good enough to get close to requirements at all freq's above 300 mHz (tilt coupling is limit)

High gain mode, ADC noise is at least 2x below sensor noise at all freq's



GS-13 for Stage 2

ADC noise - at ADC

Low gain mode good enough to get close to requirements at all freq's above 300 mHz (tilt coupling is limit)

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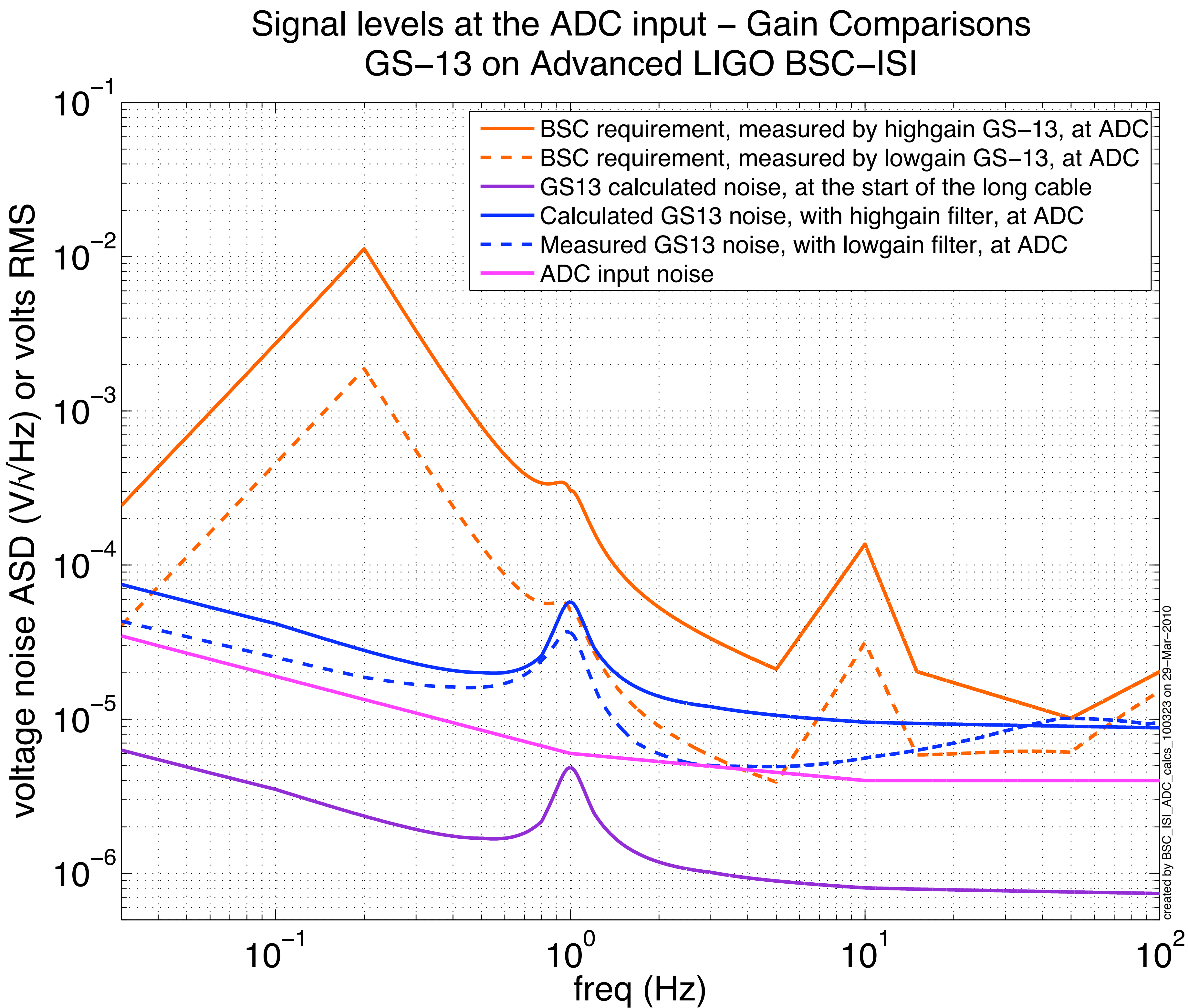
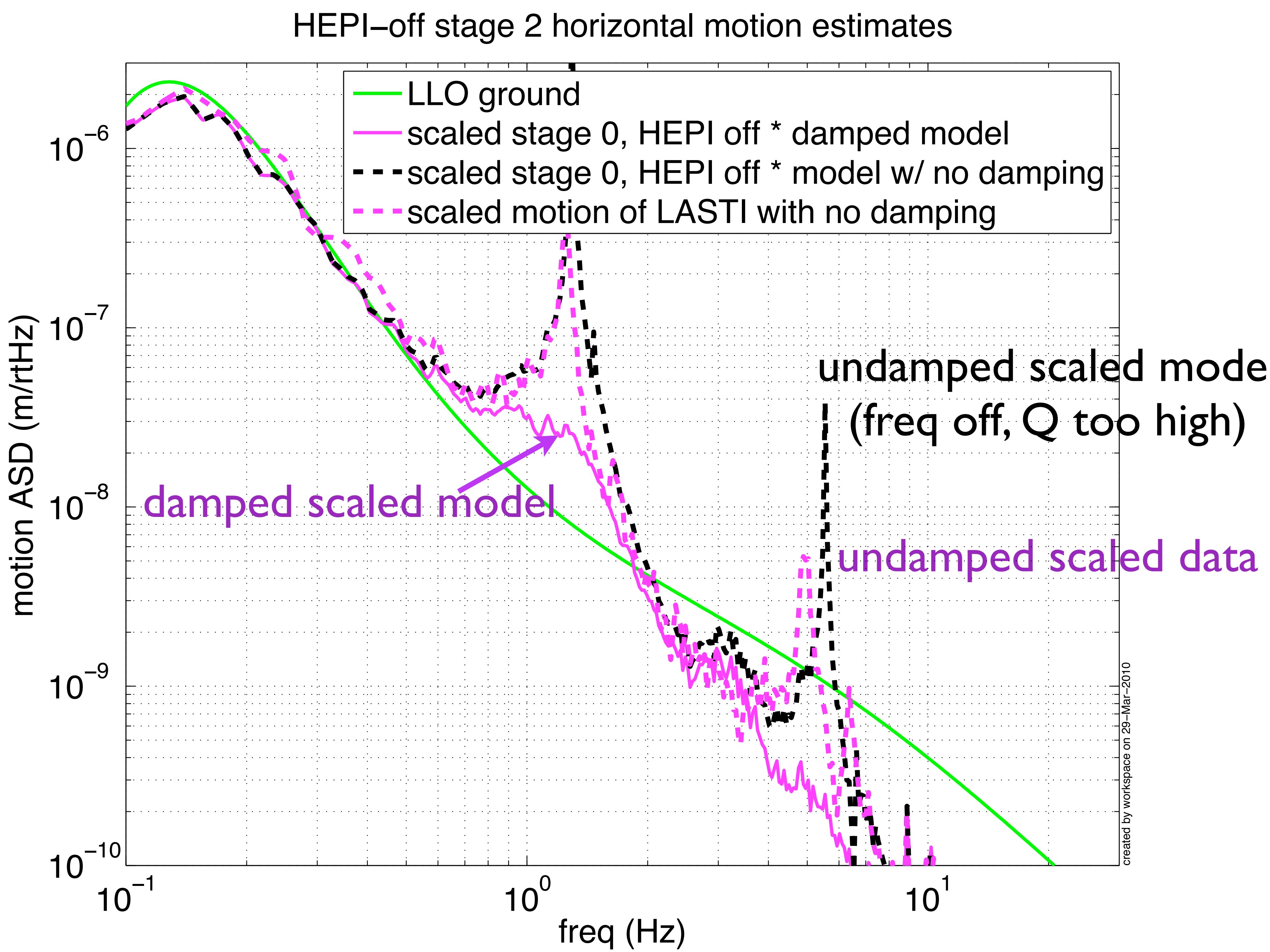


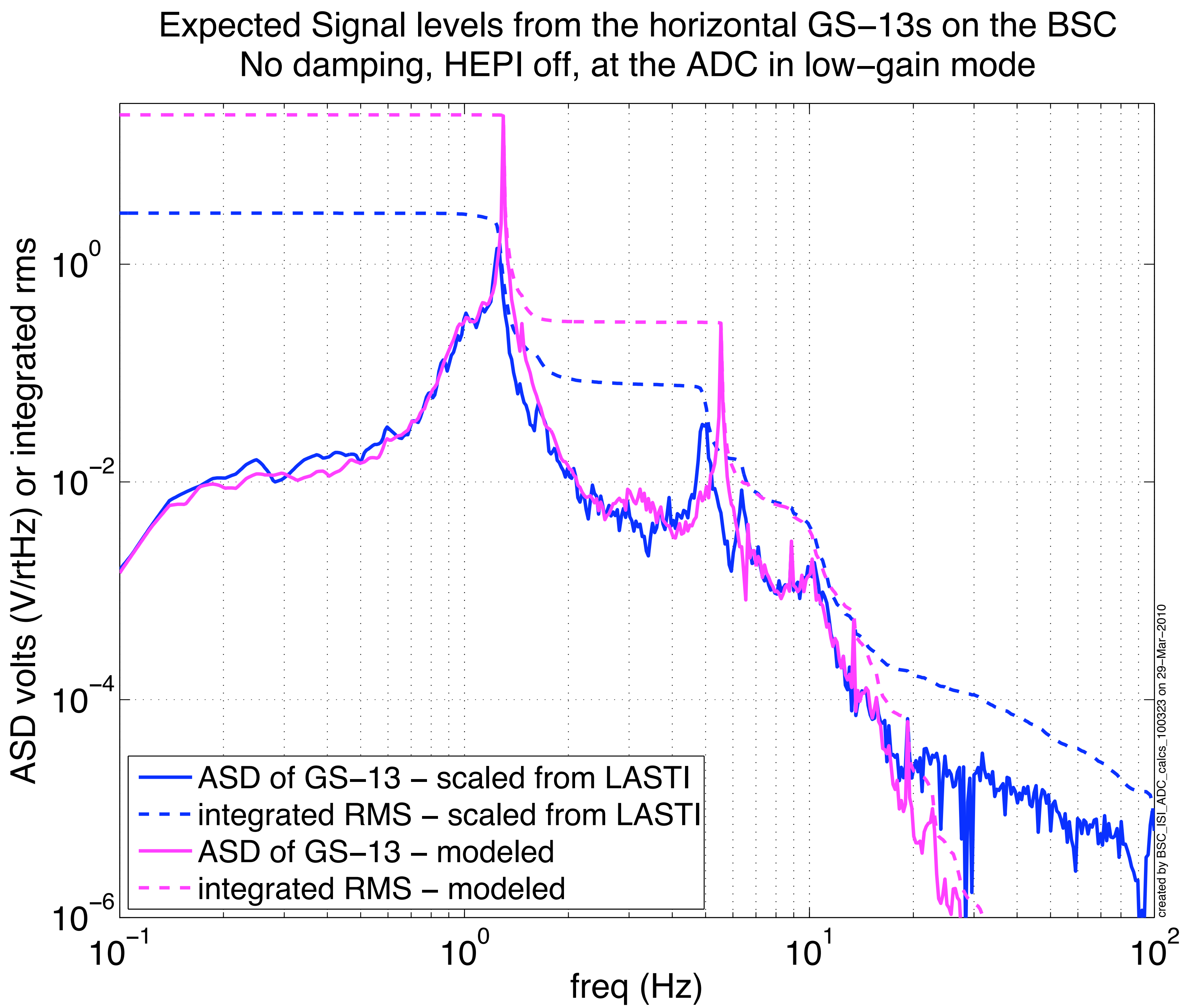
GS-13 for Stage 2

stage 2 motion inputs - low gain, no damping HEPI off
- compare model to data-
magenta is input we use



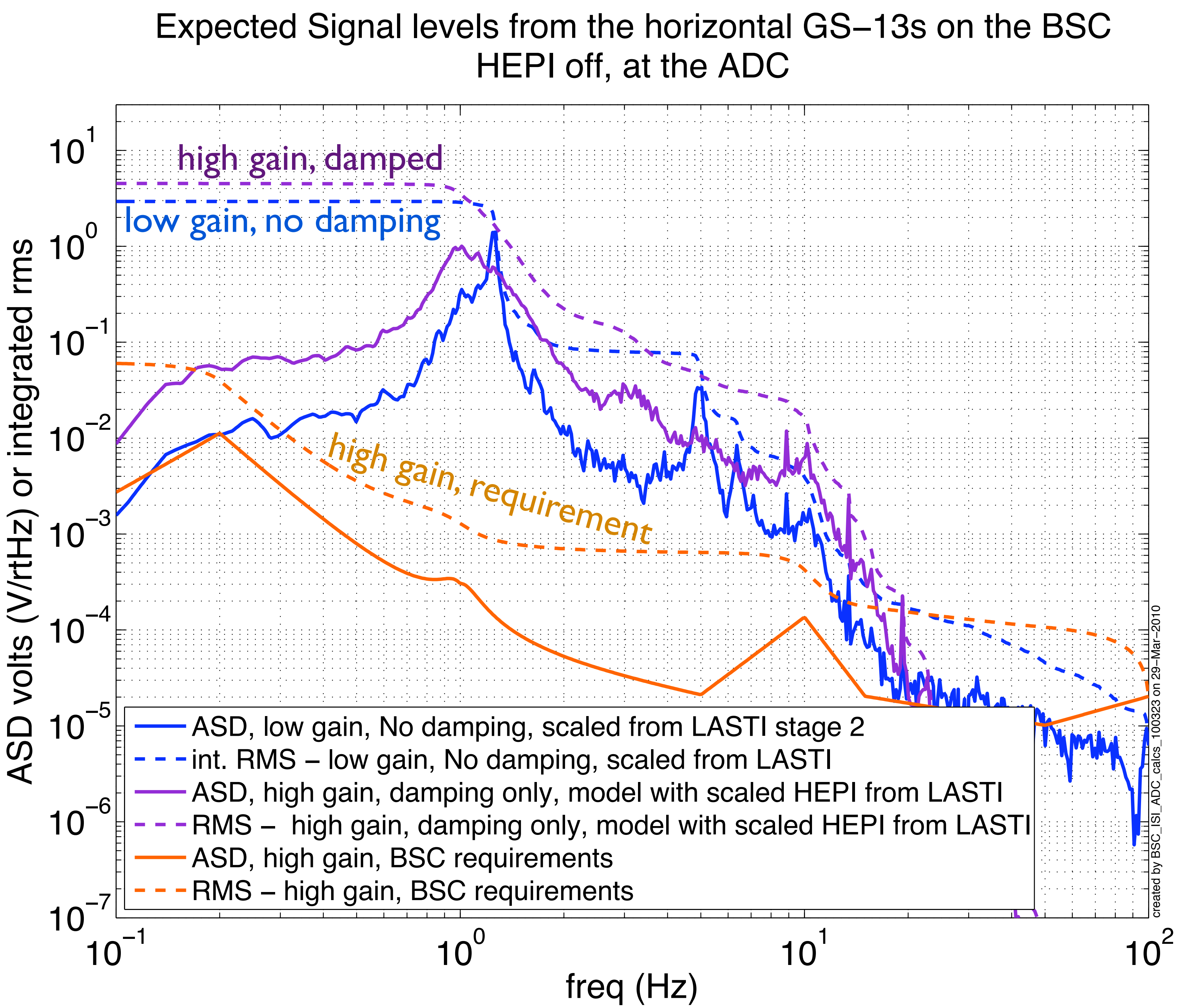
GS-13 for Stage 2

Range - low gain, no damping - compare model to data-
blue is stage 2 LASTI data scaled by the LLO ground motion.
magenta is scaled LASTI HEPI * model of undamped stage 2



GS-13 for Stage 2

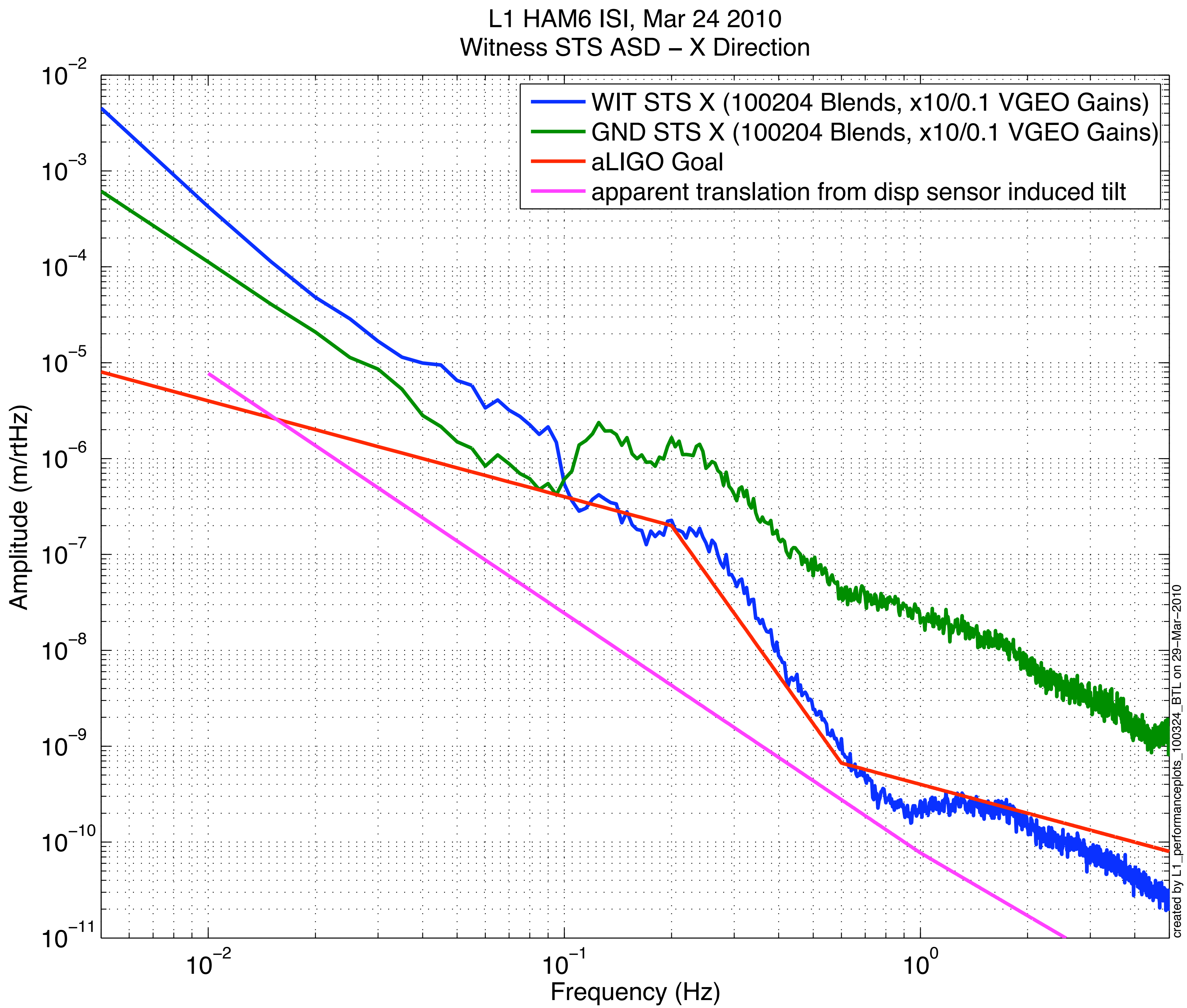
Range - RMS in various configurations.
Most commissioning must happen in low-gain. Damp stage 1 first.
Not much headroom in high-gain mode until the performance is good.



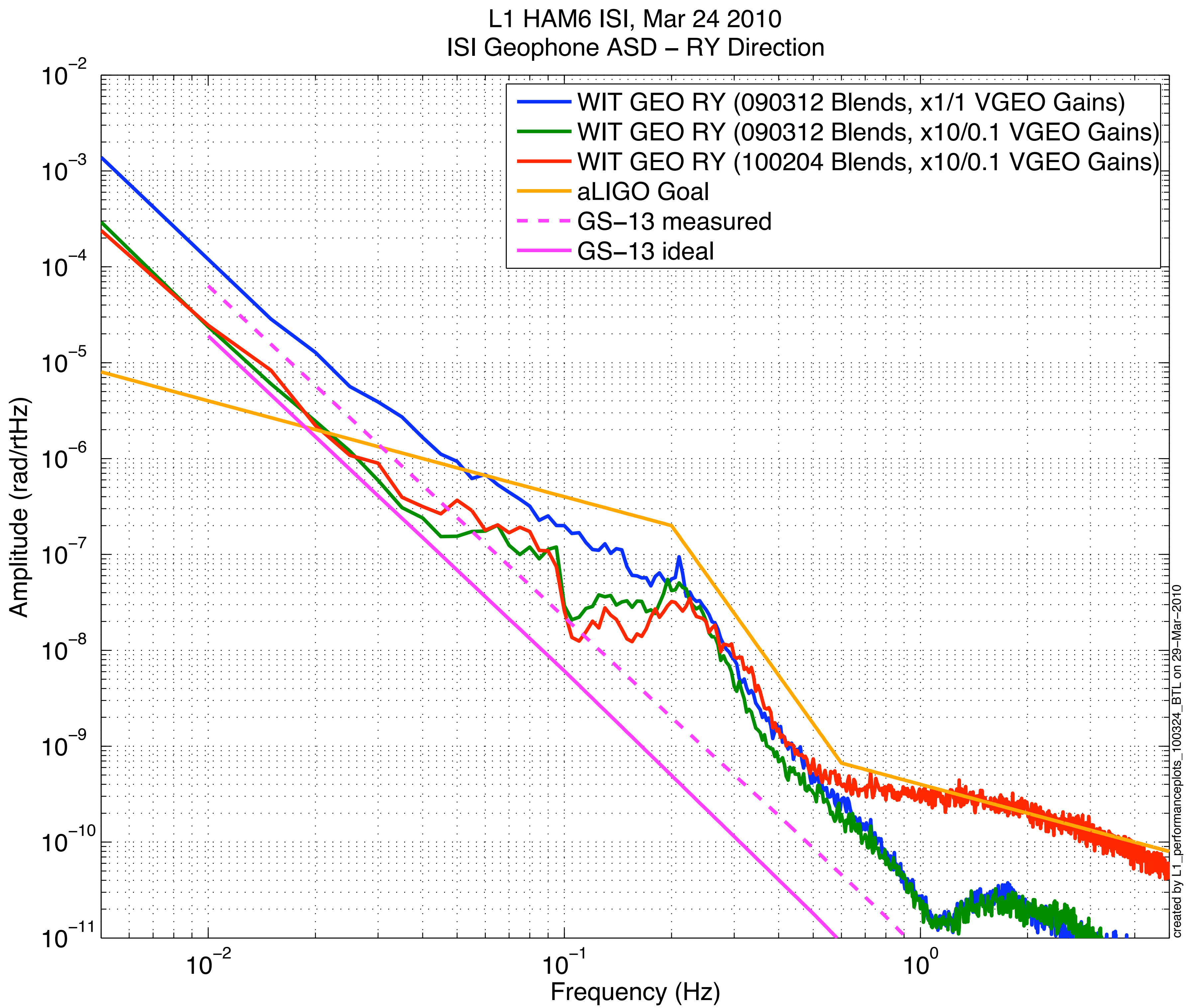
Conclusions

- Electronics should be OK.
- Goldilocks sort of design
  - too much gain reduces robustness & complicates commissioning.
  - too little gain impacts the noise performance
  - Current design is a compromise - hopefully a good one
- I would not say no to better ADCs, but we can get by with these.
- All this assumes linear noise in the ADCs. Non-linear effect of slow bit-edge crossing will require more gain at high frequencies. (Ben has a spot for these).

Additional HAM Data 1



Additional HAM Data 2



Additional HAM Data 3