LIGO

Retrofitting Strategy After S5

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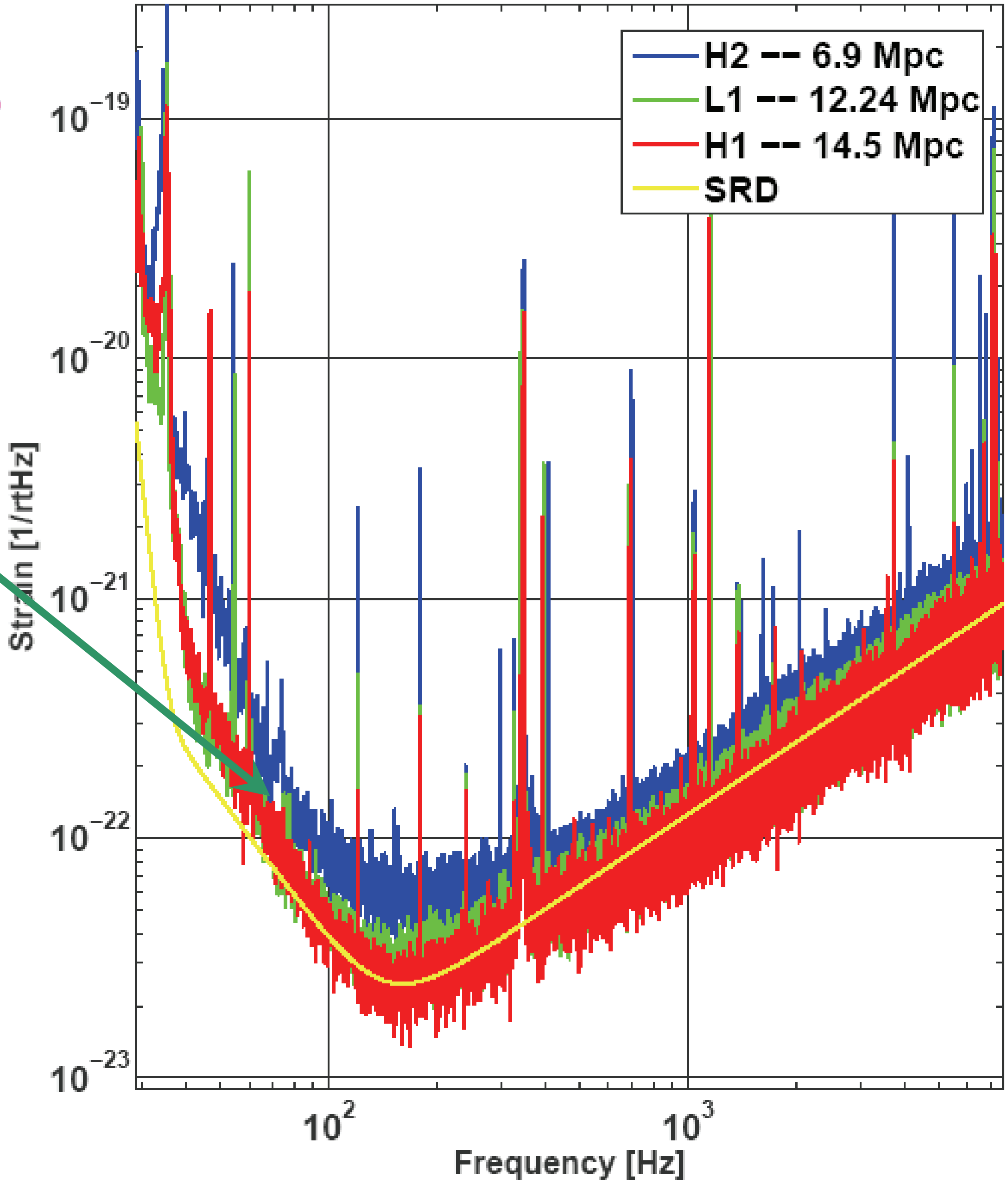
G060102-00-I

State of the Detectors

- Some improvements in the recent '2 week' commissioning period.
- Much less 'mystery' noise



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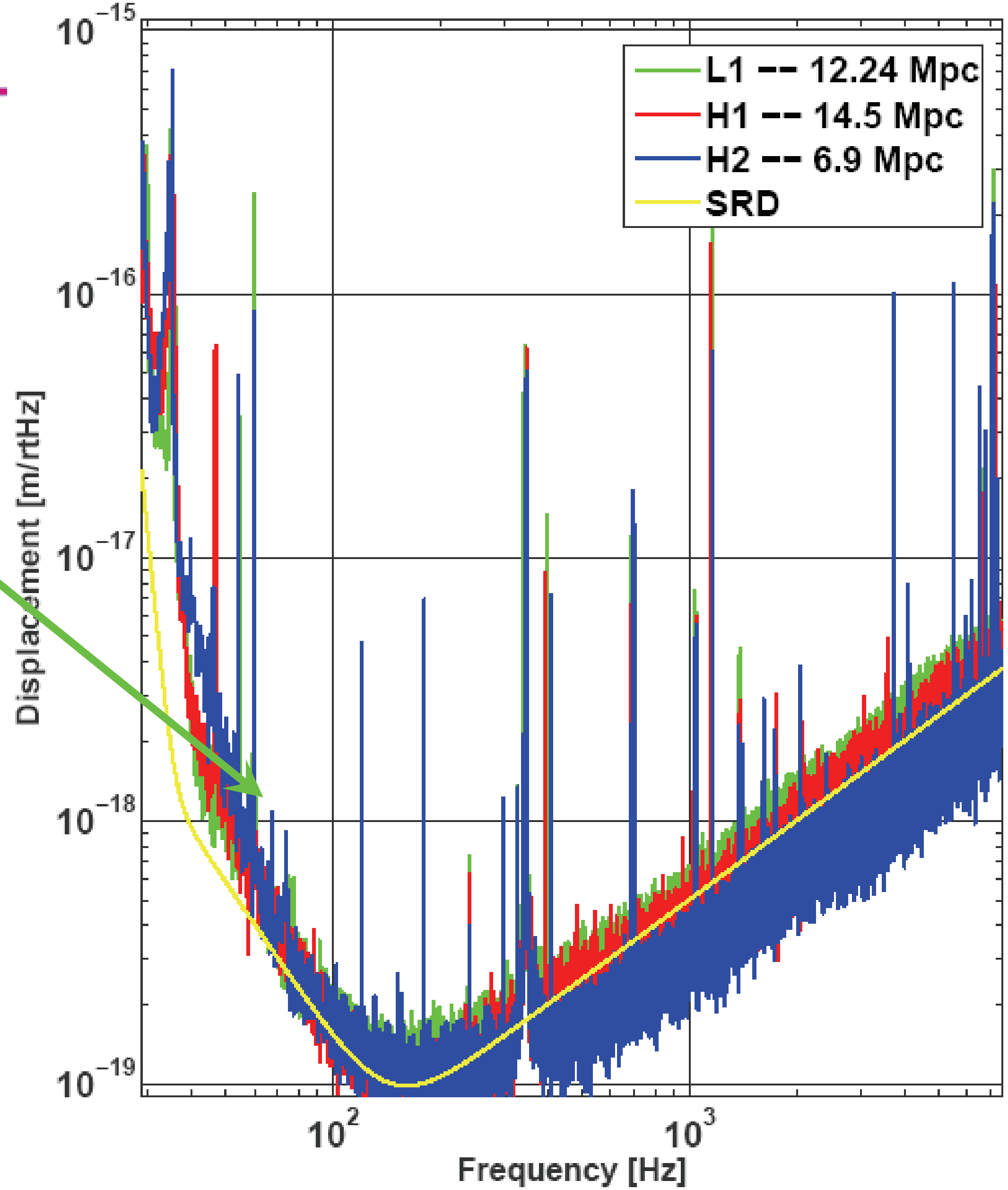
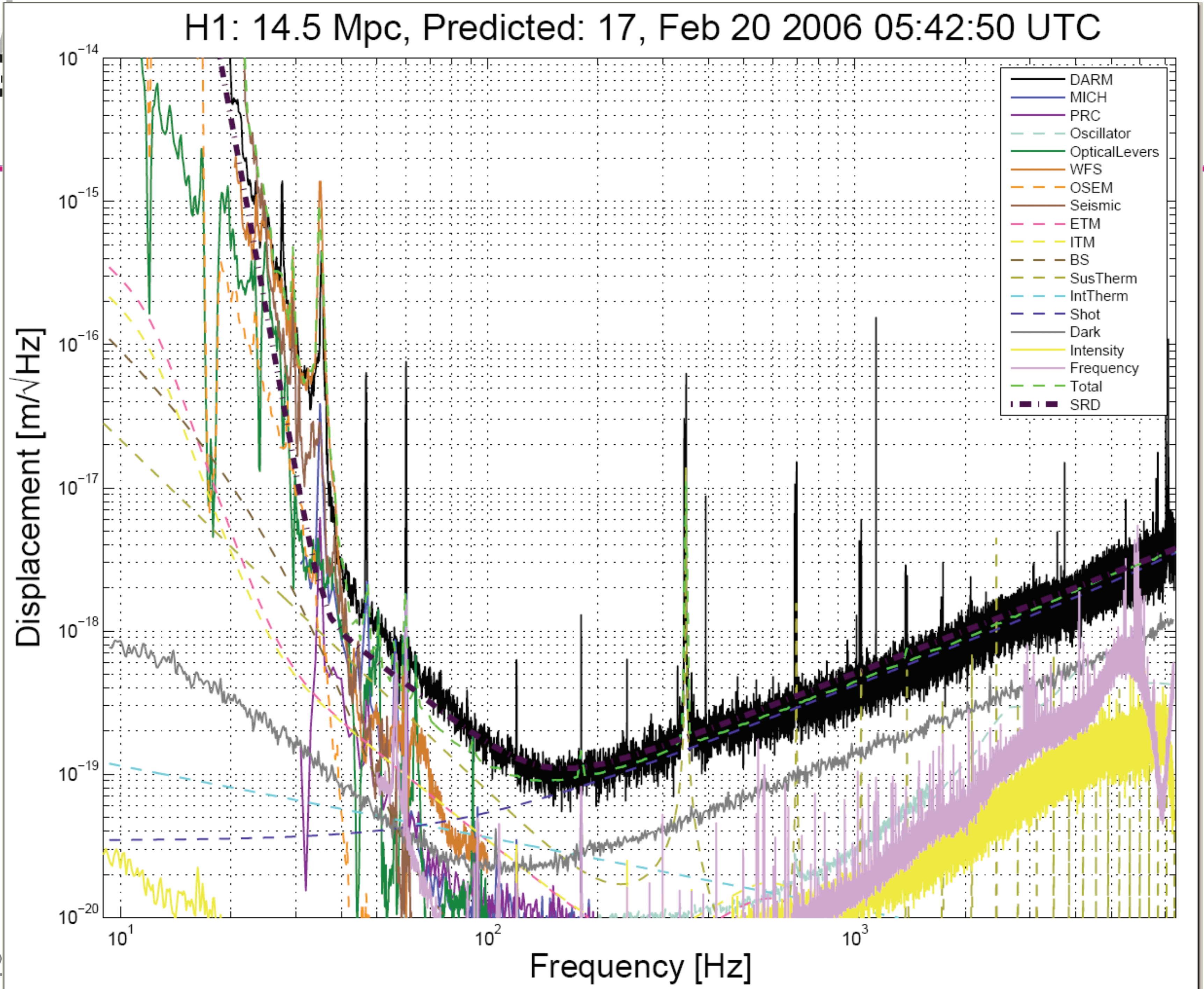
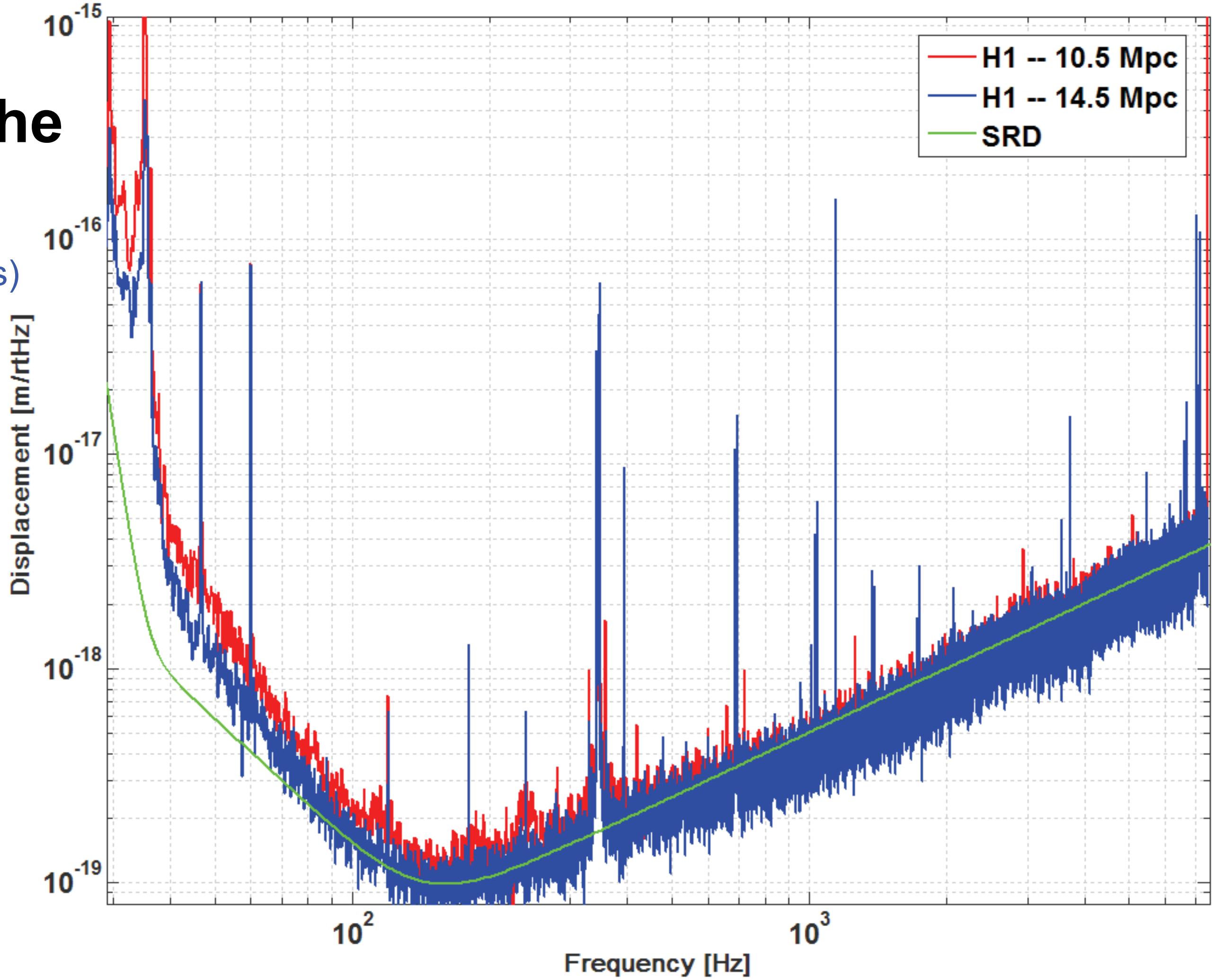



H1: 14.5 Mpc, Predicted: 17, Feb 20 2006 05:42:50 UTC
Displacement [m/√Hz]
Frequency [Hz]
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

Low frequency excess/mystery noise

Main improvement through reducing the HVAC air flow rate.

(details in R. Schofield's LHO elogs)



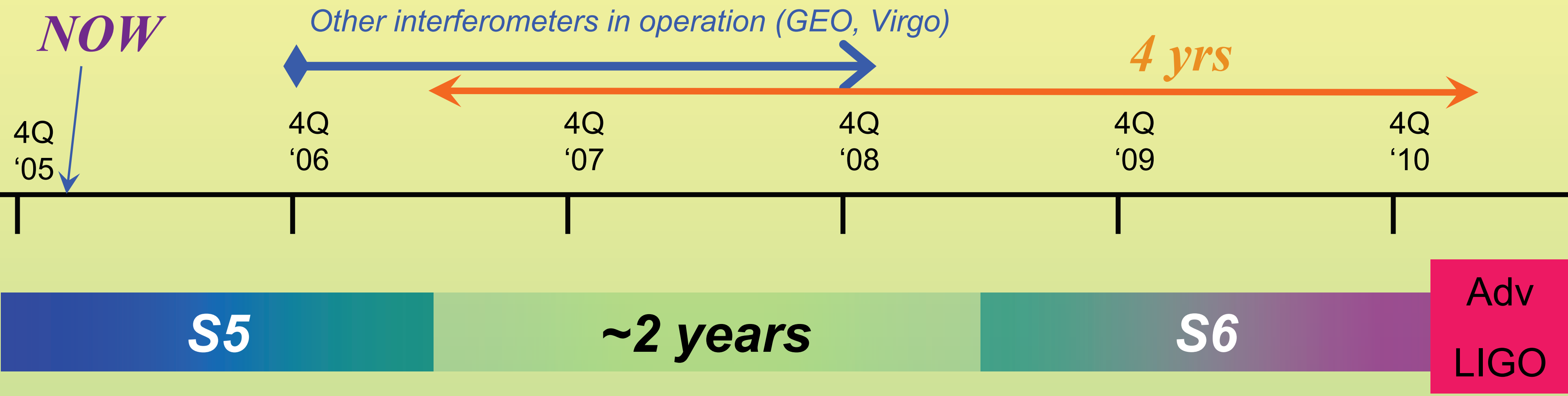
Believe it is upconversion of some sort…

- Output Electronics
- Optical (scattering)
- Mechanical

This topic needs more work before we plan too far.

LIGO

The next several years

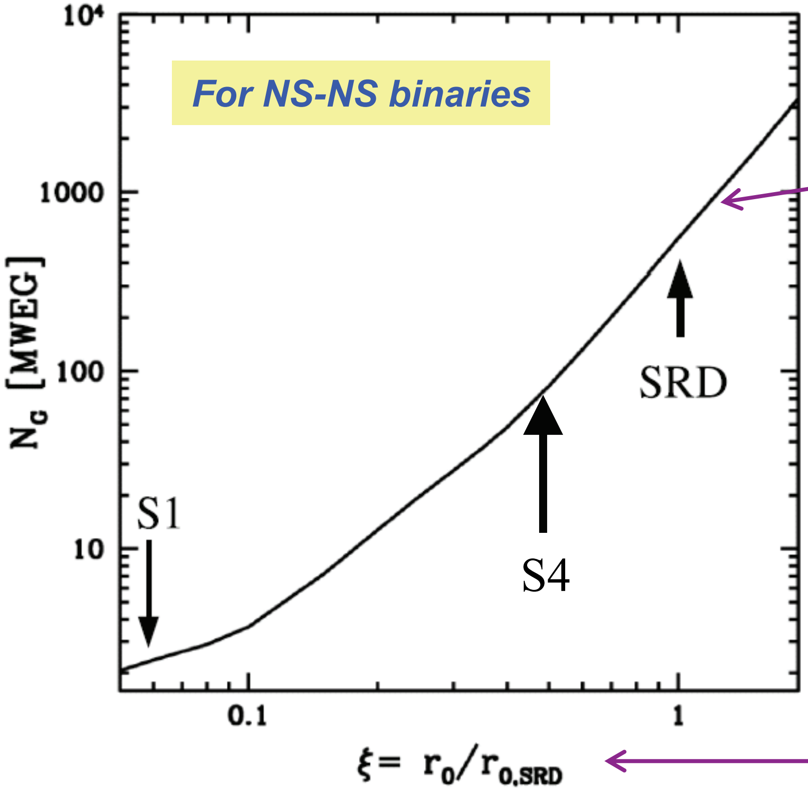


- Between now and AdvLIGO, there is some time to learn and improve and detect gravity waves…
  1) ~Few years of hardware improvements + ~1 ½ year of observations.
  1) Factor of ~2-2.5 in noise, factor of ~5-10 in event rate.
  2) Better to spend debuggin time before AdvLIGO
  3) *AdvLIGO is a HUGE step in terms of interferometry!*

Astrophysical Motivation

How does the number of surveyed galaxies increase as the sensitivity is improved?

From astro-ph/0402091, Nutzman et al.



Power law: 2.7

Factor of 2-2.5 reduction in strain noise,
⇨ factor of 6.5-12 increase in MWEG

Prop. to inspiral range

Some Considerations

- ~2 years for installation and commissioning
- ~1 ½ years for data taking
- Use Advanced LIGO technologies wherever possible
- Plan should consider contingency options for potential AdLIGO delays
- Initial LIGO components/features that are not candidates for upgrade
  - Core Optics (except possible spare replacements)
  - Isolation stacks
  - IFO beam path (e.g., no suspension change that moves the optic)
  - Vacuum system
  - Buildings/Facilities (no major changes)

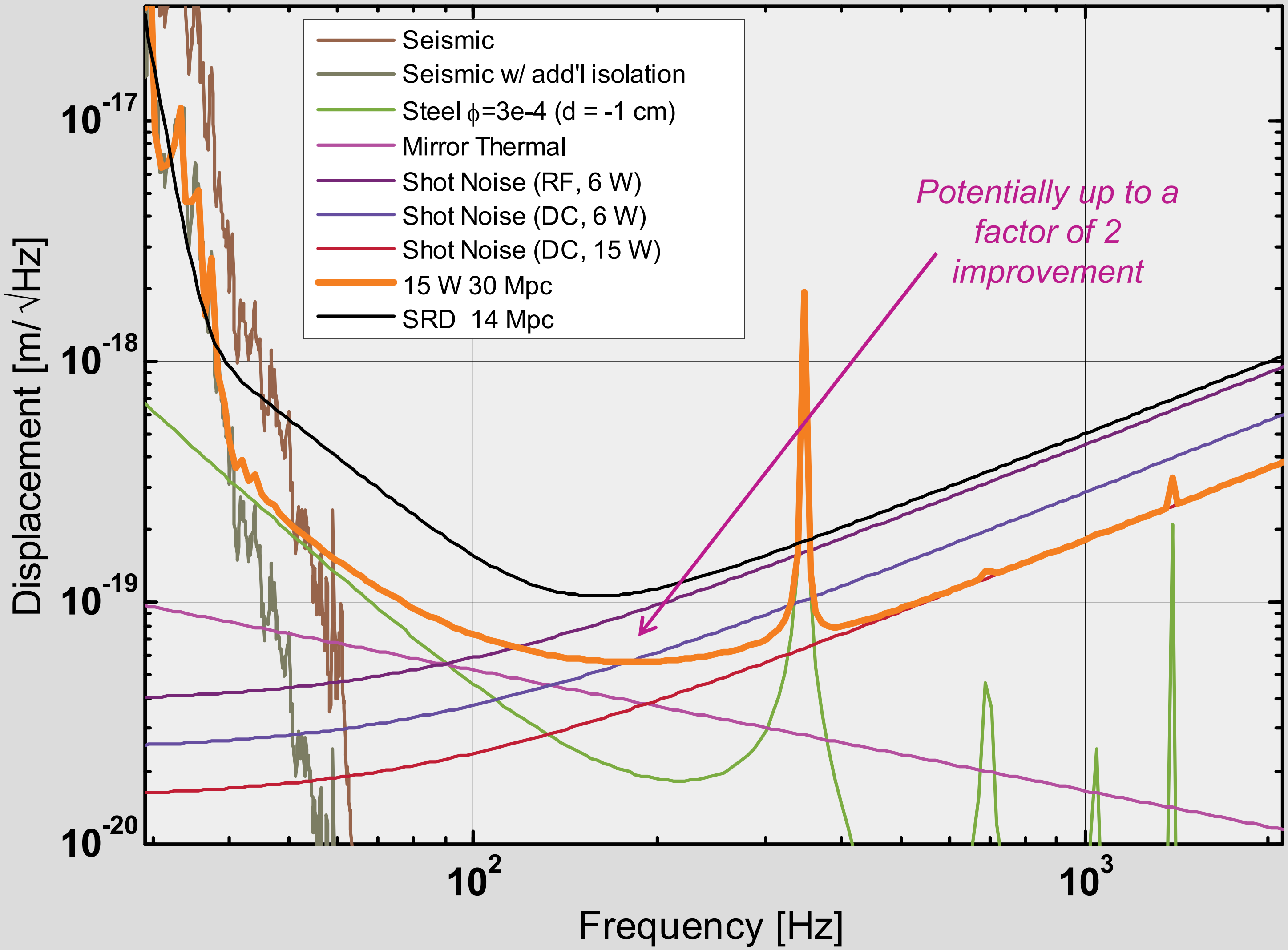
Resource constraints

- Budget
  - LIGO Lab funding for this is tight: ~ $1-1.5M, over a couple of years, available for Detector upgrades
- Schedule
  - Plan should ease (not delay) Advanced LIGO implementation
  - Feasible, debuggable upgrades
  - Should consider: what happens if AdvLIGO is delayed?
- People
  - Cannot drain time from AdvLIGO R&D team
  - Can use site staff and initial-LIGO commissioning people

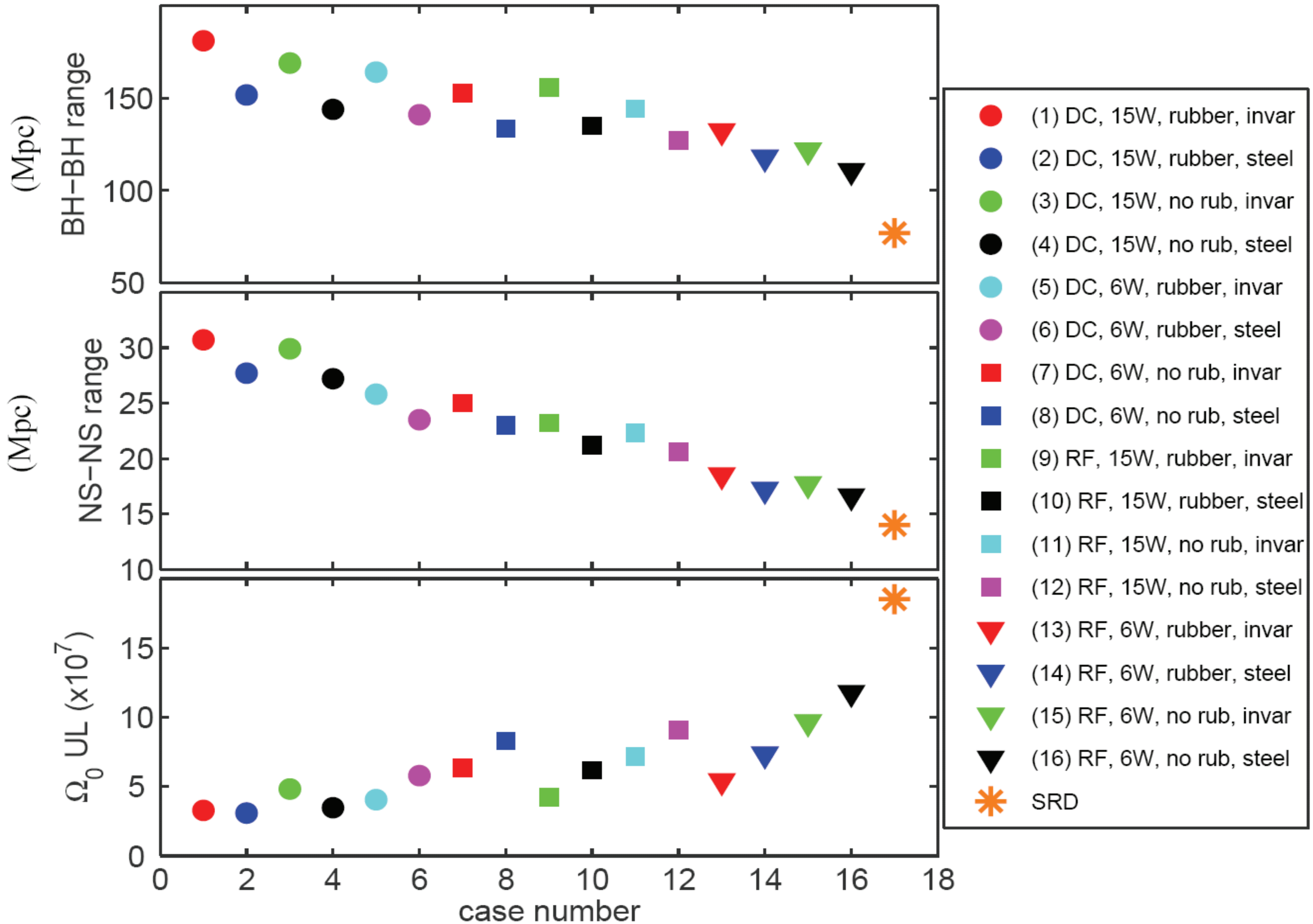
Baseline Goals

1. Output mode cleaner
    1. In-vacuum implementation
    2. DC Gravity Wave detection as in AdvLIGO (RF fallback)
    3. Possibly w/ an AdvLIGO HAM stack
2. Higher power laser
    1. Laser-Zentrum Hanover (LZH) AdLIGO technology
    2. Amplify existing MOPAs w/ commercial amplifiers
3. High Power Input Optics (Modulators/Isolators)
4. Seismic noise suppression (indirectly)
5. Suspension thermal noise improvement
6. Miscellaneous …

Fundamental noise sources for an improved detector



Various Options (4K IFOs)



GRB Ranges: 44 / 57 / 72 Mpc 2.5 / 5 / 10 M

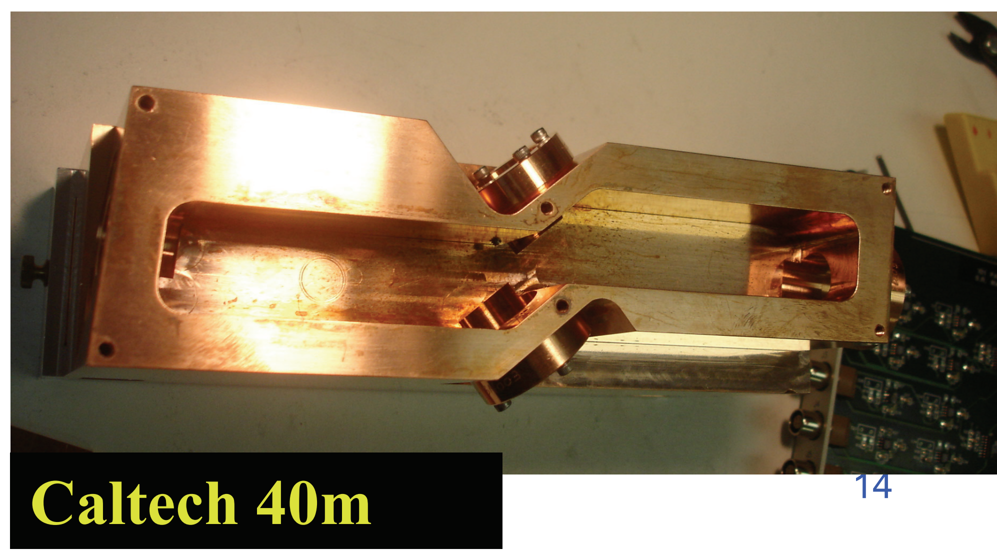
Proposed Improvements

1. Output mode cleaner
   1. In-vacuum implementation
   2. DC Gravity Wave detection as in AdvLIGO (RF fallback)
   3. Possibly w/ an AdvLIGO HAM stack
2. Higher power laser
   1. Amplify existing MOPA…
   2. w/ Laser-Zentrum Hanover (LZH) AdLIGO technology
   3. or w/ commercial amplifiers
3. High Power Input Optics (Modulators/Isolators)
4. Seismic noise suppression (indirectly)
5. Suspension thermal noise improvement
6. Miscellaneous …

Better Signal Detection: Output Mode Cleaner

Basic Motivations

- Limited by photodetector saturations; OMC removes most of the junk light
- Removing the junk light reduces shot noise
- DC Readout (AdvLIGO baseline) has technical noise benefits:
  - RF Oscillator phase noise (significant at ~few kHz)
  - Laser frequency noise (close to limiting)
- Past OMC testing on H1 showed benefits, but was ~300x too noisy
- Critical for any high power operations (H2 only uses 2.5 W of laser power)

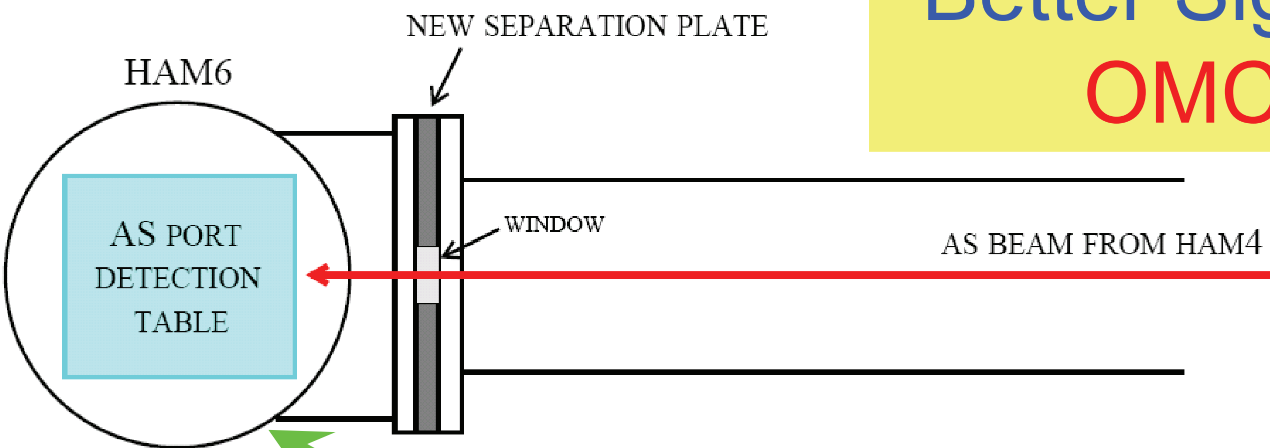


Better Signal Detection: Output Mode Cleaner

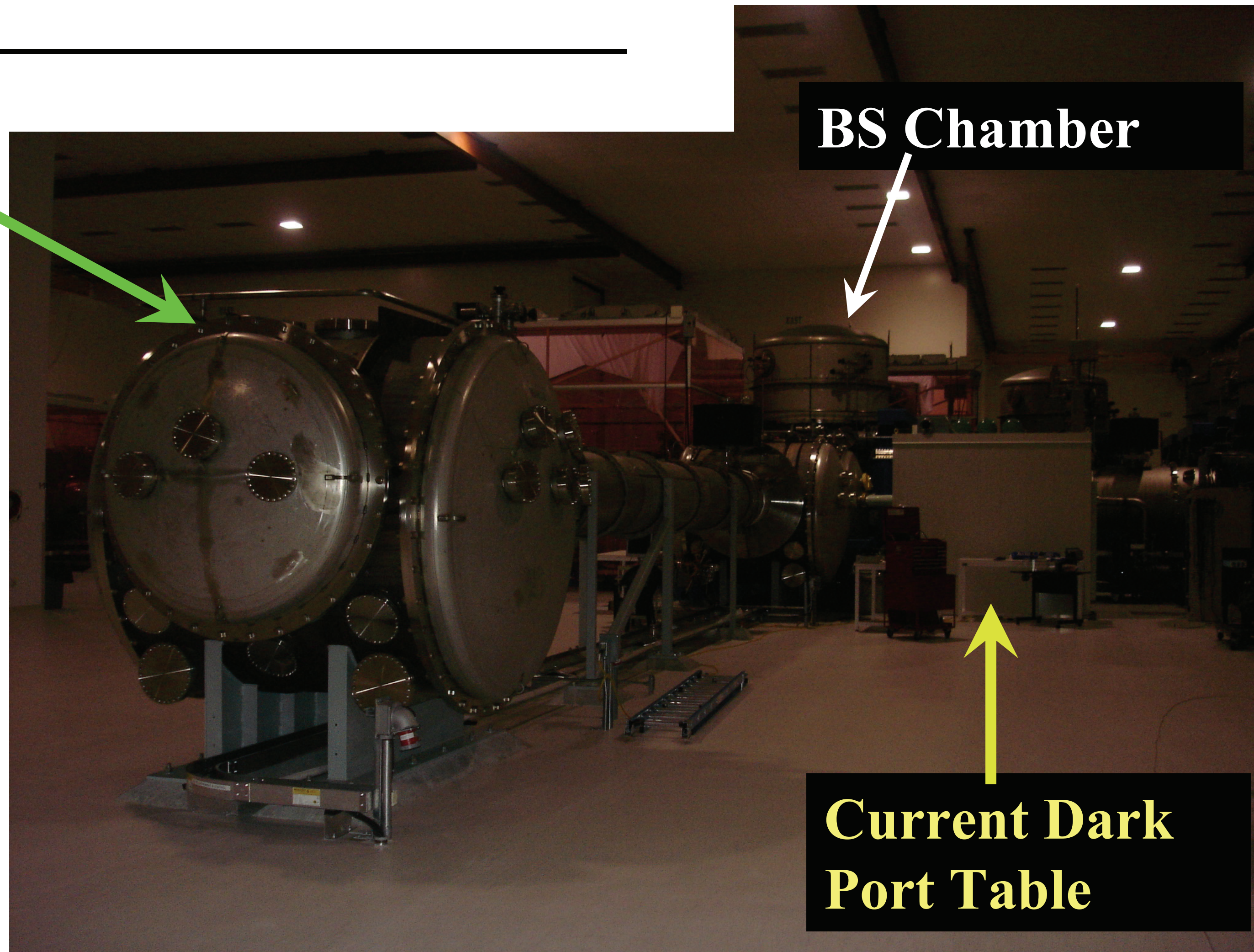
1. In-vacuum Cavity and Photodetectors*
   1. Hanford 4K experience: too much seismic/acoustic noise
   2. In an unused HAM chamber (HAM6)
   3. Baseline for AdvLIGO
2. Seismic Isolation (a few possibilities)
   1. LIGO-I style passive stack
   2. AdvLIGO HAM (2 stiff stages, 1 stiff stage, HAM-SAS)
   3. Commercial passive isolation (Pneumatic, Minus-K, etc.)
3. In-Vac Photodetectors
   1. Being developed at the 40m for the DC readout experiments
   2. Pair of 2 mm InGaAs diodes with load resistors and LT1128's
4. In-Vac Auto-alignment w/ PZTs
   1. Re-use the LIGO-I RBS PZTs (bulk of the cost)
   2. In-vac mode matching telescope w/ pico motors

* Items in blue being tested at the 40m this summer

Better Signal Detection: OMC Chamber



- Separate vacuum system
- ~1e-7 torr at least
- Design for easy access
- In-air commissioning



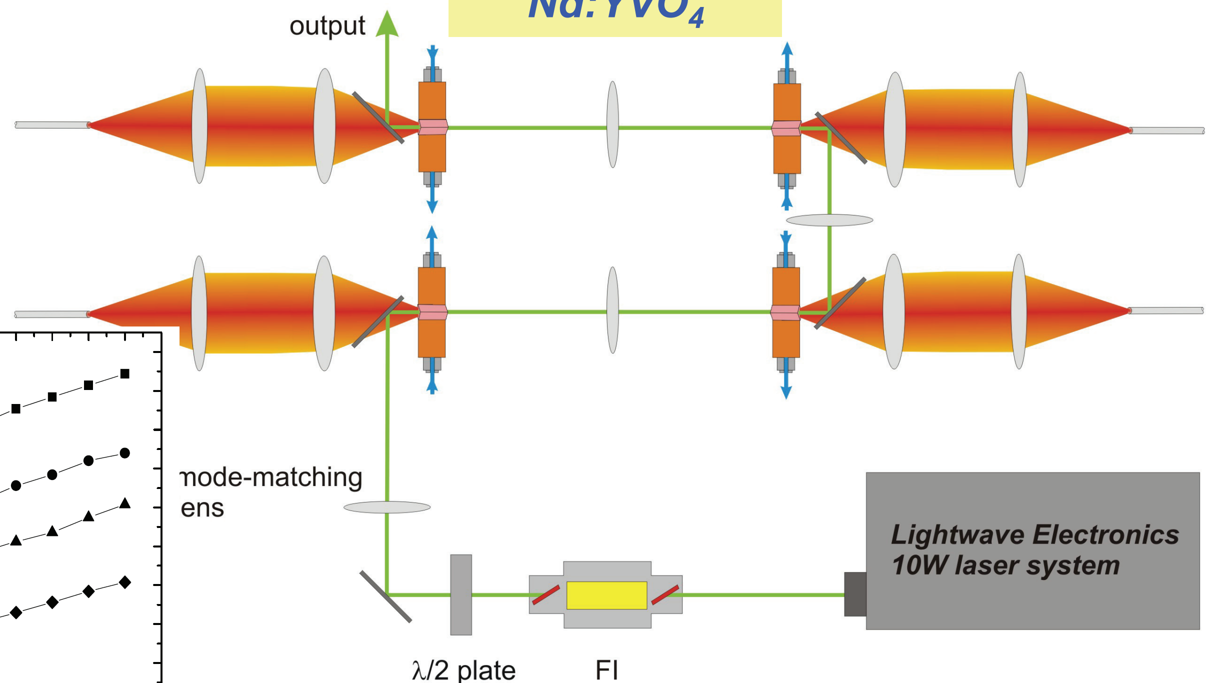
Seismic Isolation for OMC

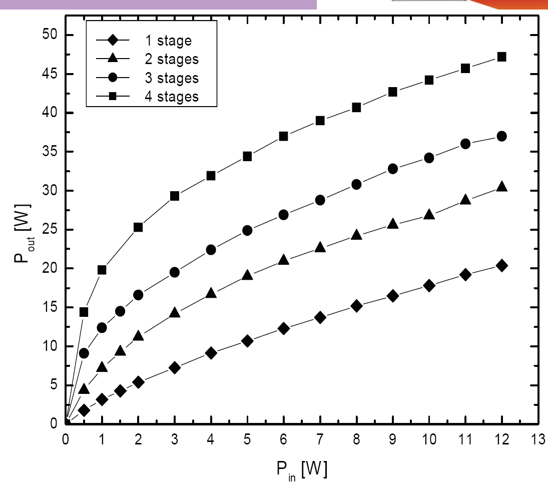
- Requirements are not well known: something ‘better’
- Cheap and simple approaches
  - Make an initial LIGO stack (or a pre-LIGO Viton stack)
  - Passive commercial system
- Advanced LIGO HAM seismic isolation system
  - Baseline: 2-stage active
  - Single stage active system (1 table or HEPI + 1 table)
  - Single stage very low frequency passive system (HAM SAS)
  - Prefer to install the AdvLIGO stack but…
  - A more costly approach, and the HAM seismic development may not be soon enough.
- OMC Suspension (see Vuk’s talk)
  - Would include OMC + Photodetectors
  - Requirements? Beam Jitter?

Higher Power Laser

- Two apparent possibilites:
  - 4-rod amplifier from LZH (front-end of the AdvLIGO laser)
  - Commercial YAG amplifiers from Northrop-Grumman
- When to start phasing these in as opposed to putting money into the JDSU MOPA's?

4 rod amplifier $Nd:YVO_4$





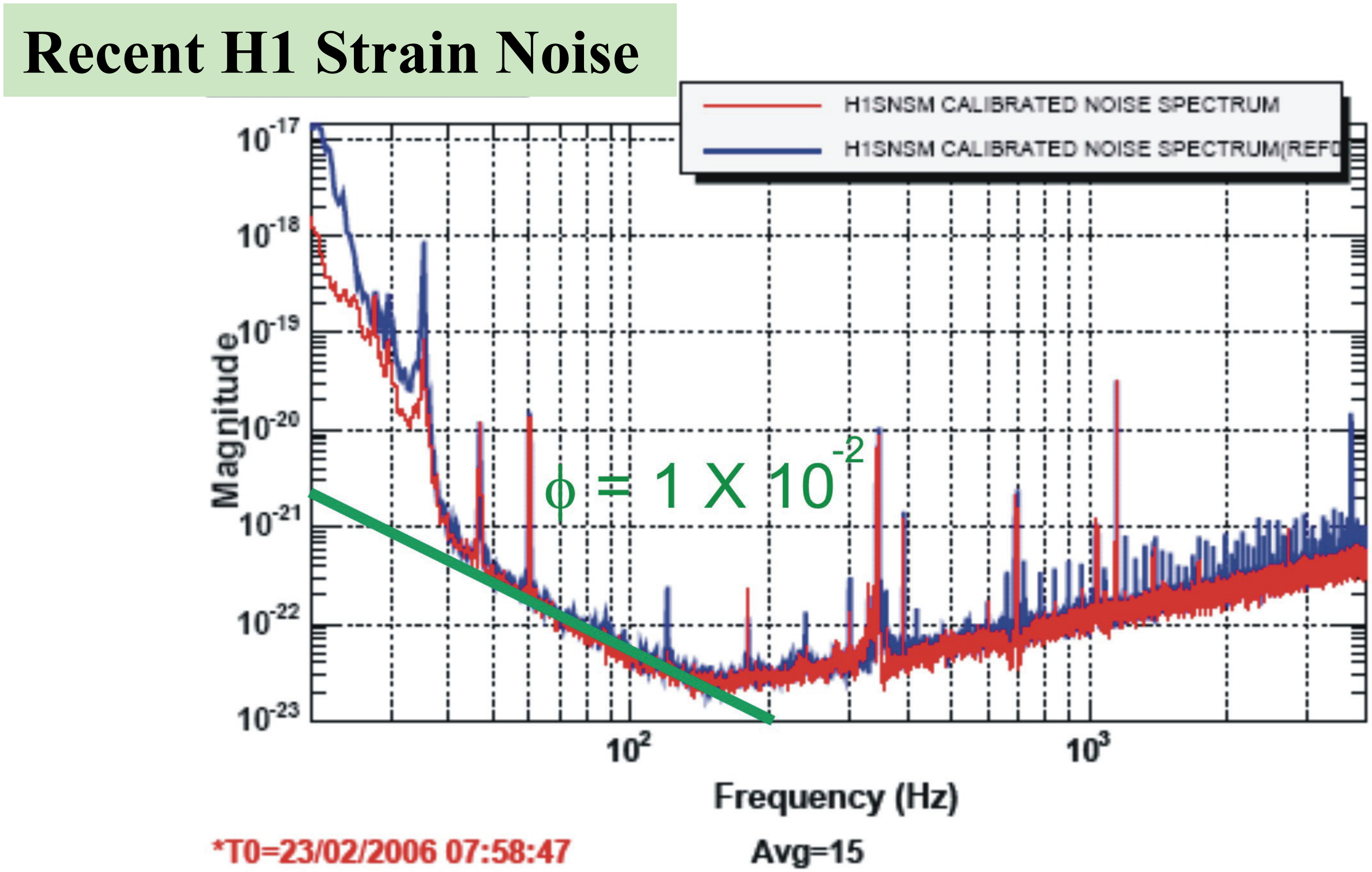
Handling Higher Power (~3x)

- ☆ Core Optics
  - ❑ Thermal Lensing
    - ❖ We are at the TCS noise limits
    - ❖ H2 cannot handle more power with existing TCS (H1,L1 are OK)
    - ❖ Need to think about ring heaters and how to do more accurate TCS
    - ❖ Wipe down more optics?
  - ❑ Radiation Pressure Effects (angular optical spring matters, really)
- ☆ Input Optics
  - ❑ Modulators (single EOM for 3 frequencies / AdvLIGO design)
  - ❑ Faraday Isolator (AdvLIGO style, similar to H2)
  - ❑ (pre) Mode Cleaners (need to be cleaned; increase throughput)
- ☆ Output Optics
  - ❑ Output Mode Cleaner removes the junk light
  - ❑ ~100 mW of light for DC readout

Seismic Noise

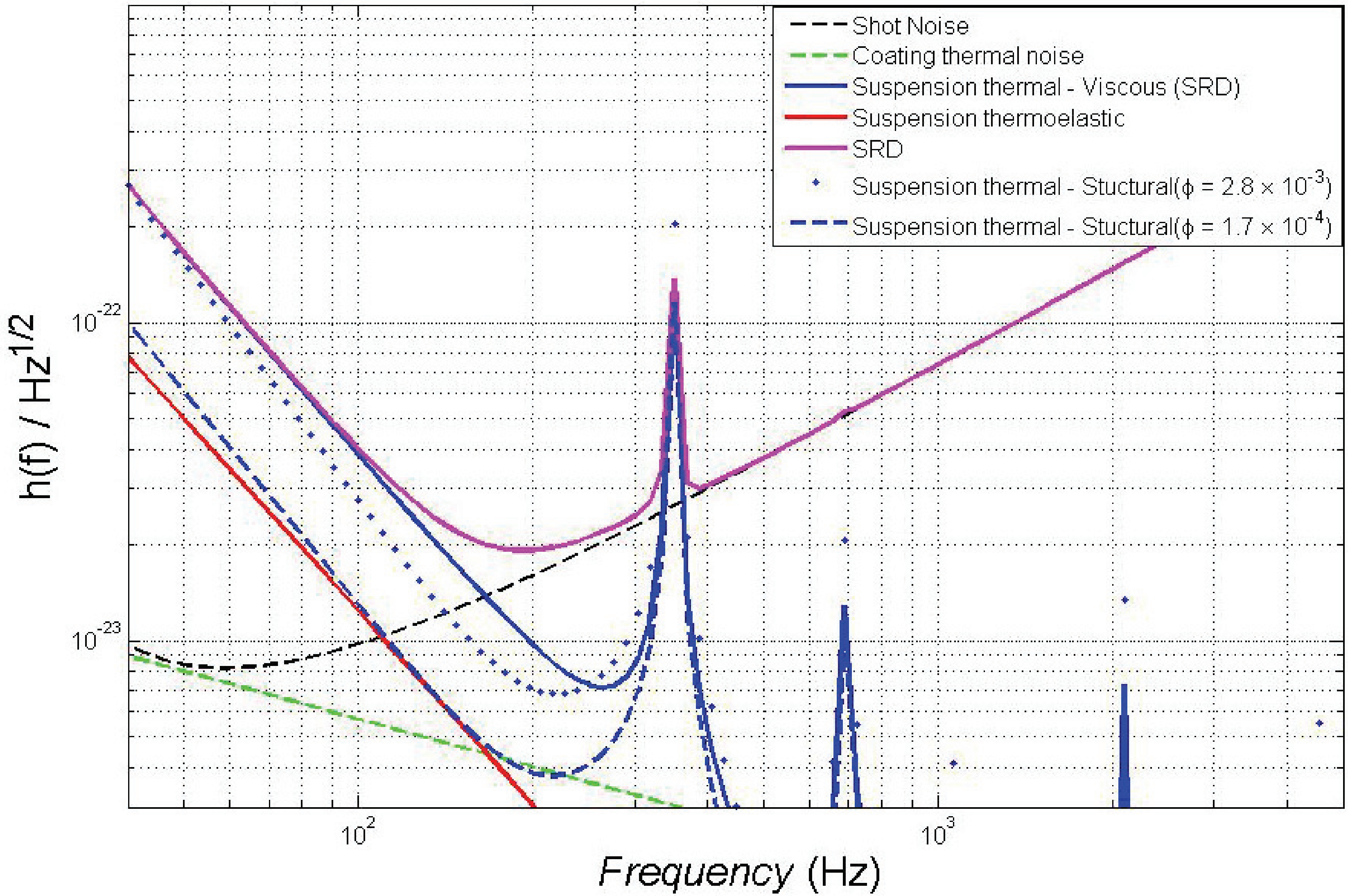
- PEPI/μFFI at LHO: less upconversion from 1-3 Hz and reduce glitch rate (as seen by the glitch group)
- More HEPI Tuning at LLO
  - Resonant gain filters
  - Different operating modes (logging mode, storm mode)
- Building Noise Remediation
  - HVAC fan flow rate shown to be tied to 50-100 Hz upconversion
  - Wind noise susceptibility; airfoils? Tents?
    - Need to study the duty cycle hit during S5 to prioritize.
- Additional passive isolation at the pier top to lower the seismic wall frequency

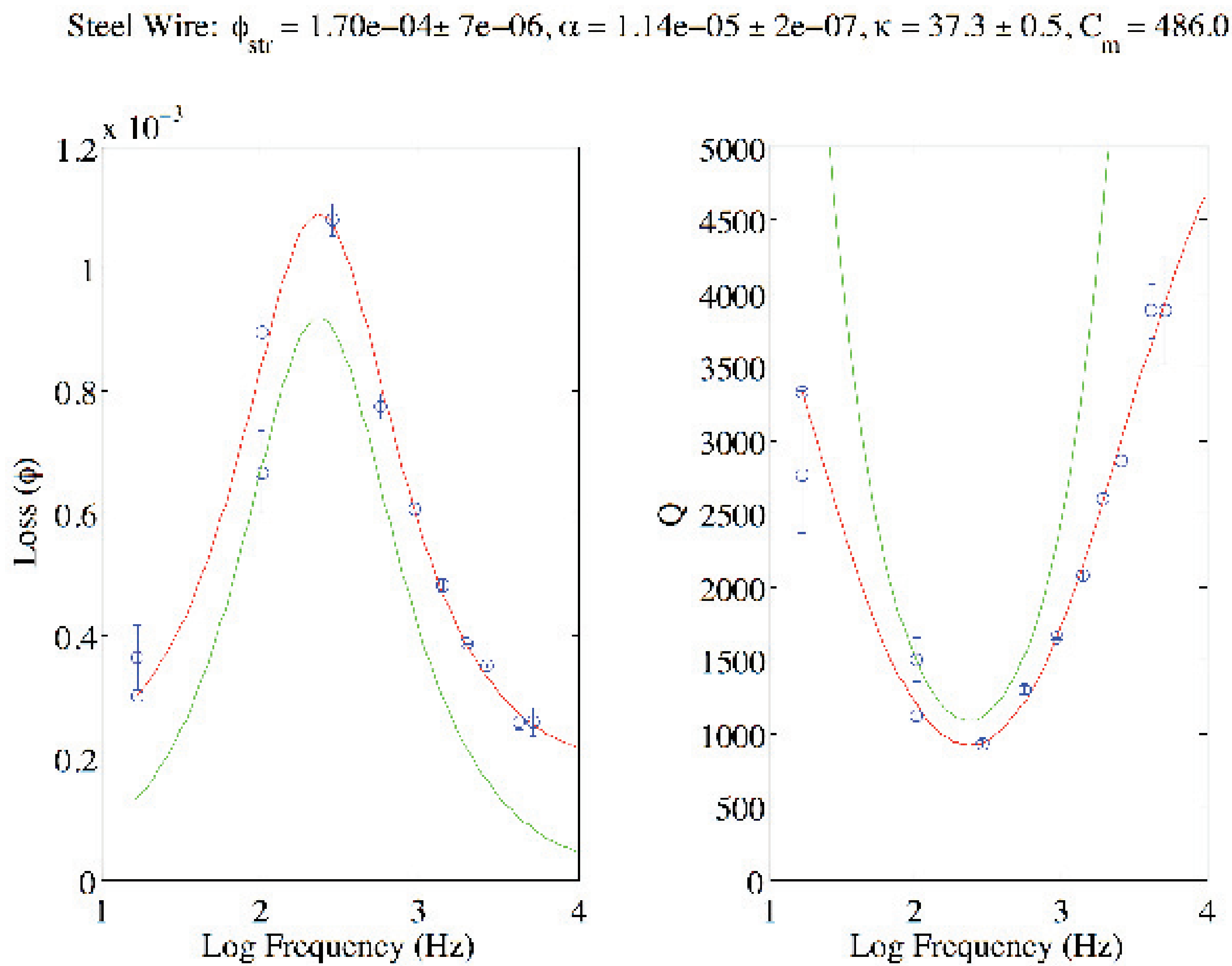
Suspension Thermal Noise

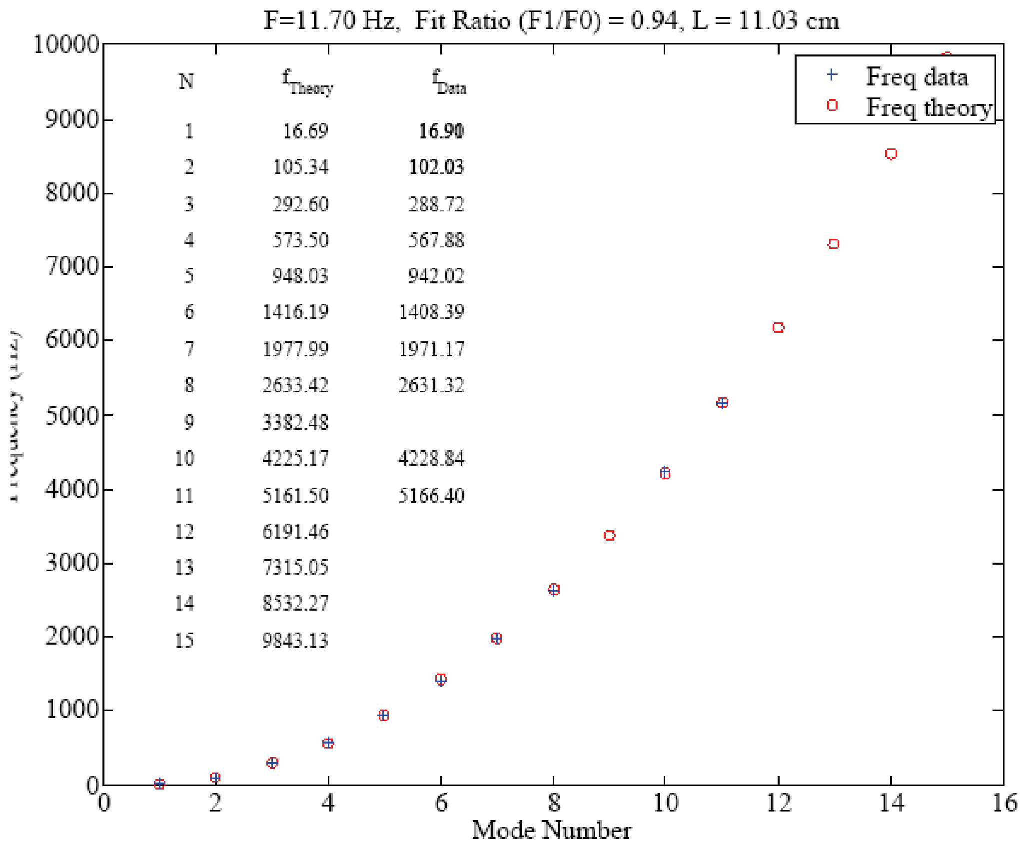


Worst wire loss inferred from *in situ* violin mode measurements: $\phi = 5.6\ 10^{-3}$

Thermal Noise in Initial LIGO




Steel Wire: ϕ_{str} = 1.70e–04± 7e–06, α = 1.14e–05 ± 2e–07, κ = 37.3 ± 0.5, C_m = 486.0
x 10^{-3}
Loss (ϕ)
Log Frequency (Hz)
Q
Log Frequency (Hz)


F=11.70 Hz, Fit Ratio (F1/F0) = 0.94, L = 11.03 cm
N f_Theory f_Data
1 16.69 16.90
2 105.34 102.03
3 292.60 288.72
4 573.50 567.88
5 948.03 942.02
6 1416.19 1408.39
7 1977.99 1971.17
8 2633.42 2631.32
9 3382.48
10 4225.17 4228.84
11 5161.50 5166.40
12 6191.46
13 7315.05
14 8532.27
15 9843.13
Freq data
Freq theory
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
Mode Number

Sensitivity Effects of Suspension Thermal Noise

	Binary Neutron Star	Binary Black Holes $(10M_o)$	Stochastic	Crab Pulsar ε
SRD	16 Mpc	60 Mpc	$4.1\ 10^{-6}$	$1.8\ 10^{-5}$
$\phi = 2.8\ 10^{-3}$ Typical *in situ*	19 Mpc	75 Mpc	$2.8\ 10^{-6}$	$1.6\ 10^{-5}$
$\phi = 1.7\ 10^{-4}$ Wire material limit	27 Mpc	120 Mpc	$6.6\ 10^{-7}$	$6.8\ 10^{-6}$
Thermoelastic limit	29 Mpc	135 Mpc	$4.6\ 10^{-7}$	$5.7\ 10^{-7}$

Single Interferometer Values

Enhancements that may address robustness or low-freq noise

- Scattered light control
  - End station beam tube baffles may be tried during S5
  - Vertex beam tube baffles: new ones would need to be made to accommodate the TCS lasers and installed (post-S5)
- Seismic isolation of detection tables
  - Already limiting the WFS noise on H1
  - Pneumatic system installed on H2
  - Put WFS1 in vac? Isolate symmetric port table? Move WFS2 in vac?
- Fast stabilization of beam pointing on detection tables (included for AS port as part of OMC work)
- Suspension Actuation Electronics rework
  - More filtering -> lower noise
  - Re-align some test masses to reduce large angle bias currents

Beyond 'Fixes'

- Suspension wire re-working
  - Change the clamp to reduce excess noise (no evidence so far)
  - Change the wire to reduce the intrinsic noise
  - Needs some serious coil driver redesigns capitalize on lower noise.
  - Need to know more about the excess noise first.
- Squeezed Light
  - Implement on one IFO instead of the laser upgrade; more speculative, but doesn't require new IO equipment.
  - An opportunity to commission another AdvLIGO system
- Signal Recycling
  - No real sensitivity improvement; lots of work.
- Double Suspension
  - Not directly applicable to AdvLIGO. Substantial reworking req.
  - Not clear if we can get the technical noises out of the way.

Need to Decide on a Plan

- What improvements should we go for?
  - Topic introduced and initial ideas presented at the March 2005 LSC meeting
  - White paper on enhancements written (T050252) and distributed to LSC in November

- What's the strategy for implementation?

Weighting a few Categories

- Sensitivity Improvements
- Increased Duty Cycle
- Implementation of AdvLIGO technology

Plan #1a

- Install OMC/HAM system on L1 after S5
- H1/H2 continues Science running w/ Virgo
- Get L1 back on the air then do H1/H2 OMCs
- Laser/IO installed on L1 as soon as H1 or H2 is on.
- Laser/IO work on H1 after L1 is up.

Slow, conservative plan. Allows for maximal debugging for repeating mistakes. Maintains coincidence with Virgo/GEO at all times for maximum detection 'safety'.

Plan #1b

- Install OMC/HAM system on H1/H2 after S5
- L1 continues Science running w/ Virgo
- Get H1 back on the air then do L1 OMC+Chamber.
- Laser/IO installed on H1 as soon as L1 is on.
- Laser/IO work on L1 after H1 is up.

Same as Plan #1a, but with the installation order swapped. Different expertise between observatories may favor one plan over the other.

Plan #2

- Simultaneous OMC installation on L1 with Laser/IO work on H1/H2 immediately after S5.
- Simultaneous OMC installation on H1/H2 with Laser/IO work on L1.
- Install baffles, re-align test masses, do wipe downs.

Faster plan. Still allows finding problems before propagating them. No coincident running with Virgo until S6.

Plan #3

- Bundle all in-vac together: OMC window, MC clean, Faraday, Baffles, COC re-alignments
- Install laser on H2 while H1/L1 resume science running
- Install IO/laser on H1/L1 while H2 runs w/ Virgo

Some downtime after S5, but maintains some coincident runtime.

Plan #4

- Mainly work on just H1/L1 - only minor work on H2
- Plan for OMC -> IO -> Laser installation
- Some modest Suspension electronics fixes
- Then some more science running.

Its probable that if try to do all 3, we'll fail miserably.

A factor of 2.5 on H1/L1 is better than a factor of 2 on all three.

After the pumpdown, H2 can join Virgo in a science run.

5 Phase Execution

- Vent (almost all of the in-vac work)
- Pump Down (OMC, End stations, PSL/IO)
- Noise Reduction (recover ~15 Mpc)
- New Laser (swap and slowly ramp up power)
- Noise Reduction

Initial Vent

- Install HAM6 flange/viewport (J. Worden, K. Ryan)
- Faraday Isolator (UF + Malik)
- Arm Cavity Baffles on ITMs (D. Cook, B. Bland)
- Clean the MC (UF + B. Bland)
- Re-Align the ITMs w/ PAMs (D. Cook, B. Bland, Sigg)
- New Laser Electronics Install (R. McCarthy)

Time Budget => 1.5 Weeks

(based on historical data from LHO vents)

Pump Down Phase

- OMC stack + optics install (H. Radkins, K. Kawabe)
- Vent Ends (Baffles, re-align ETMs) (D. Cook, B. Bland)
- New EOM (UF + R. Savage)
- PMC replace (R. Savage, J. Garofoli)
- Float ISCT1 (R. Schofield, Ski)
- SUS Bias Module change (R. McCarthy, J. Myers)

Time Budget => 8 Weeks

(based on historical data from LHO vents)

Recover the Sensitivity

- DC Readout / OMC system commissioning w/ Michelson
- Recover Full IFO locking using AS RF pickoff
- Reduce Noise (get better than S5 sensitivity)

Failure is Not an Option

This is a critical AdvLIGO must-have technology test.

Time Budget => ***16 Weeks***

(based on high confidence in the LHO staff)

Higher Power Laser

- New Laser Install (R. Savage, C. Vorvick, D. Cook)
- Tune up the PSL servos (J. Garofoli, R. Savage)

Time Budget => 3 Weeks

(based on historical data from elogs)

Move to Full Sensitivity

- High Power Operations (New PDs, New ASC)
- Tune up IFO for stability, not noise
- Reduce Noise (get better than S5 sensitivity)
- SUS Electronics fixes (coil drivers)

Failure is Not an Option

This is a critical AdvLIGO must-have technology test.

Time Budget => ***28 Weeks***

(based on high confidence in the LHO staff)

Who's working on what

- Output Mode Cleaner System
  1. Overall Integration / Layout (D. Sigg)
  2. DC PD's (B. Abbott, R. Adhikari)
  3. DC OMC design (R. Ward, R. Adhikari)
  4. RF OMC design (K. Kawabe ?)
  5. OMC alignment system (S. Waldman)
  6. OMC Suspension / modeling (V. Mandic)
  7. HAM
     1. Passive stack (nobody)
     2. AdvLIGO 1 or 2-active stage (Giaime, Lantz, et al)
     3. HAM-SAS (DeSalvo, et al)
- Higher power laser
  1. LZH Amplifier (LZH, B. Willke)
  2. CEO amplifiers (J. Giaime, D. Ottaway, + students)

Who's working on what (cont.)

- Seismic Noise Suppression
  1. PEPI (M. Landry, R. Mittleman)
  2. HEPI Tuning (S. Wen, B. O'Reilly, J. Giaime)
  3. Building Noise (R. Schofield, J. Worden, B. O'Reilly)
  4. ISC Table Isolation (P. Sarin, R. Mittleman, R. DeSalvo, R. Schofield)
  5. Fast ISC Table Alignment system (S. Waldman, K. Kawabe)
- Suspension Studies / Rework
  1. Characterizing initial LIGO SUS (S. Penn, G. Harry, F. Raab)
  2. New wire suspension design (S. Penn, G. Harry, R. Weiss, F. Raab)
- Coil Driver Noise Reduction
  1. SUS alignment plan (D. Cook, B. Bland, G. Traylor, D. Coyne)
  2. New bias modules (R. Weiss, R. Abbott)
  3. Coil Driver redesign (R. Abbott, K. Watts, R. Adhikari)

LIGO

Who’s working on what (cont.)

- Upconversion Studies
  1. Output Electronics (V. Sandberg, V. Frolov)
  2. Seismic (R. Schofield, B. O’Reilly, S. Wen)
  3. Scattering (R. Schofield, R. Weiss, B. O’Reilly)
  4. 60 Hz mitigation (R. Schofield, R. Weiss, M. Zucker, K. Watts)
  5. Fast ISC Table Alignment system (S. Waldman, K. Kawabe)
- Thermal Compensation Upgrade
  1. Better techniques (P. Willems, D. Ottaway)
  2. Modeling (H. Yamamoto, P. Willems)
- New ASC System
  1. Spring Compensation (R. Bork, D. Sigg, S. Waldman, R. Adhikari)
  2. Modeling (H. Yamamoto, V. Mandic)

After some success…

- ☆ Suspension Thermal Noise
  - ❑ Wires, Blocks, Clamps (depends on recommendations by SUS)
- ☆ Seismic Platform Interferometer
  - ❑ PZT mirrors mounted on the stacks (maybe just for LLO)
  - ❑ Testing the idea for AdvLIGO (gives very LF stabilization)
- ☆ Squeezing
  - ❑ How long will it take? Trade 5 months for 3 dB in noise?
  - ❑ Some prototyping at the 40m in the next few years
- ☆ New Controls Code
  - ❑ ASC Code for optical torque compensation
  - ❑ New LA code imported from the 40m (no more g-ratios !!)
  - ❑ HF Digital controls for PMC, ISS, MC
- ☆ Stable Recycling Cavity for the 2K

End

- Need to get an email response from each Search group.
- Budget still being made.
- ….