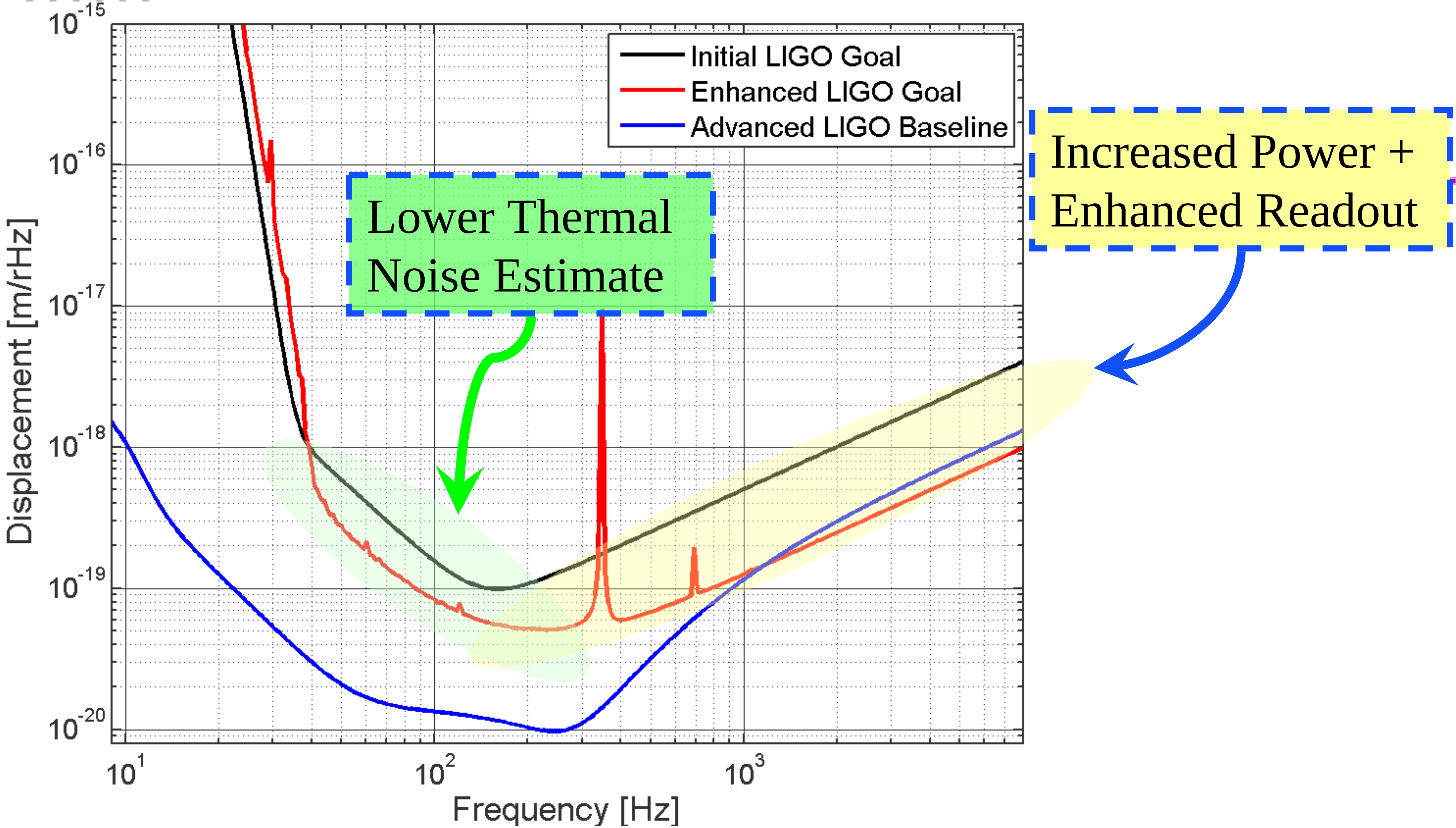
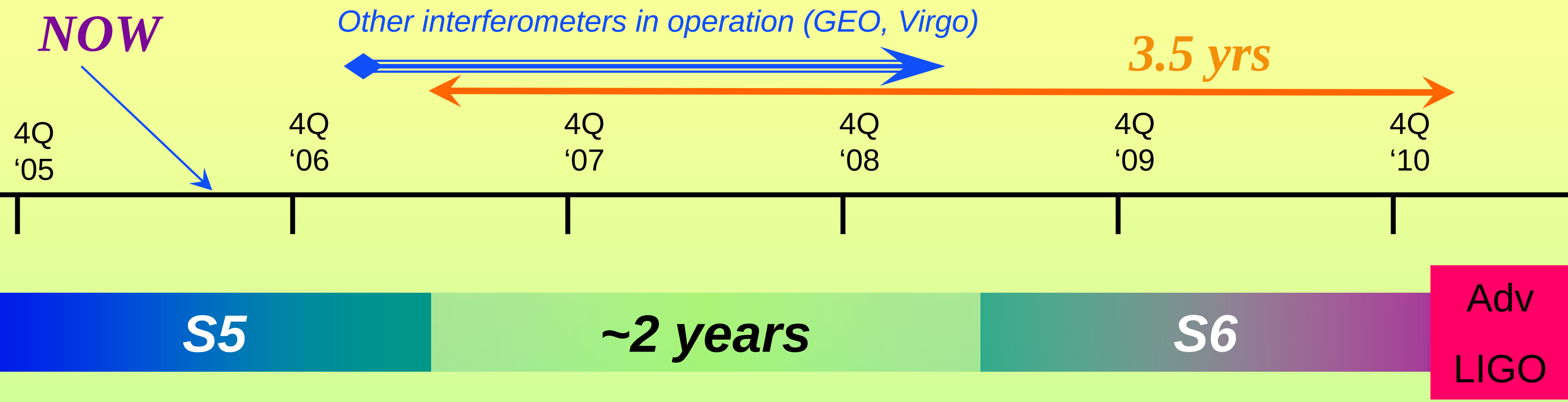
Enhanced LIGO



- Noise improvements are mainly above 100 Hz
- Requires good control of technical noise
- NS/NS Ranges: 15 Mpc, 30 Mpc, 200 Mpc

TIME



- **Enhanced LIGO goals =>**
  1) Factor of ~2.5 in noise, factor of ~5-10 in event rate. Dramatic increase in the probability of a gravitational wave detection.
  2) Debug new AdvLIGO tech in the only low noise interferometer available.
  3) Reduce the AdvLIGO commissioning time (find bugs now).

What to Enhance?

- ~2 years for installation and commissioning
- ~1 ½ years for data taking

Not These:

- Core Optics: Very good contrast, moderate recycling gain. High cost, high risk, low payoff.
- Vacuum: No serious problems. Nothing to fix.
- Facility: HVAC turbulence and wind susceptibility are being studied.
- Beam Path: Lot of work for not so much payoff (e.g. Signal Recycling)
- Isolation Stacks: Huge low frequency amplification, but good attenuation above ~30 Hz. Made acceptable with PEPI/HEPI solutions.

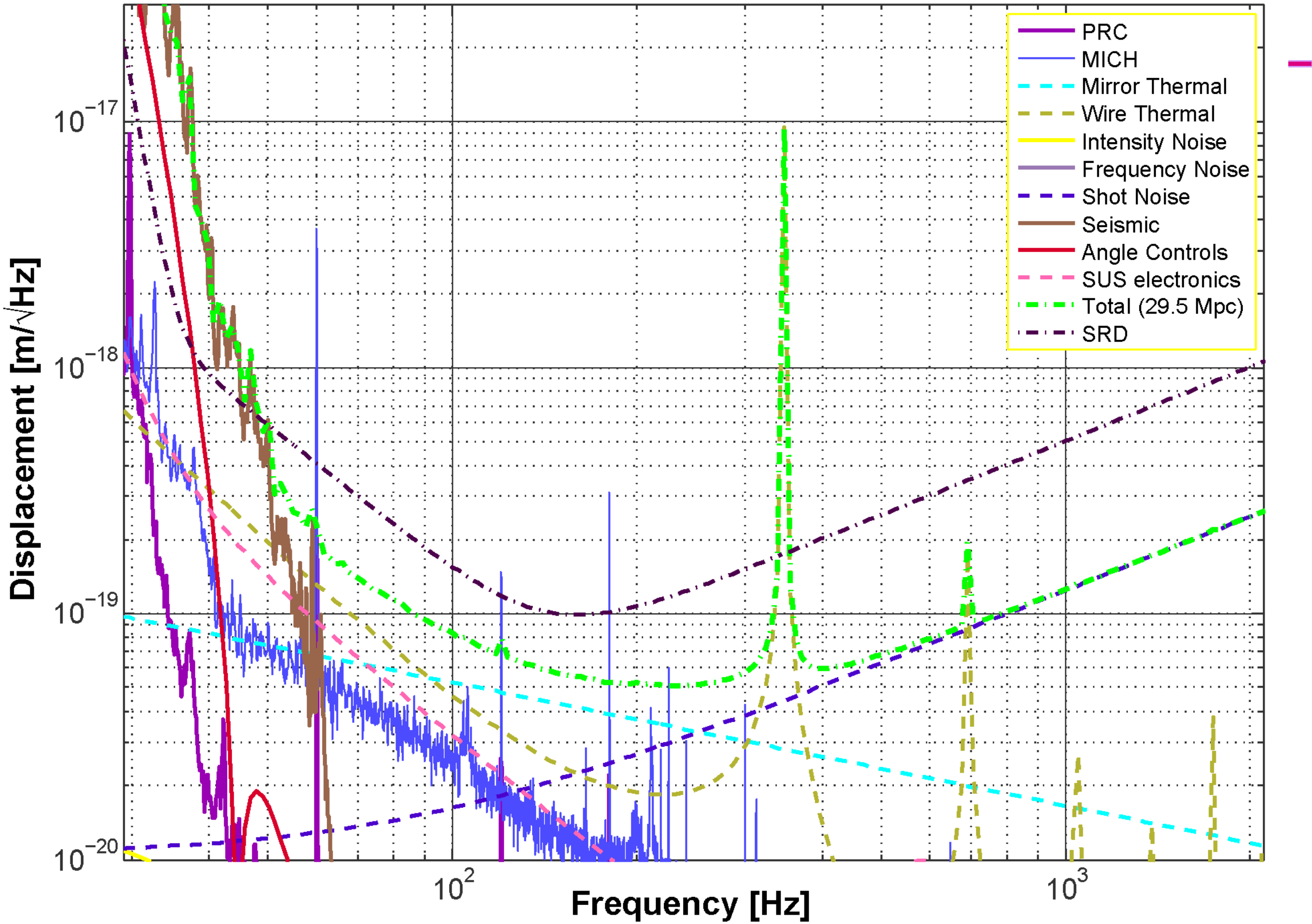
Resource constraints

- Budget
  - ~ $1.5M, over a couple of years, available for Detector upgrades
- Schedule
  - Plan should ease (not delay) Advanced LIGO implementation
  - Feasible, debuggable upgrades
- People
  - Limited number of available people
  - Plan to leverage the accumulated experience of the site staff
  - R&D expertise utilized adds to experience for AdLIGO
  - Strong commissioning support from campus staff and grad students

Baseline

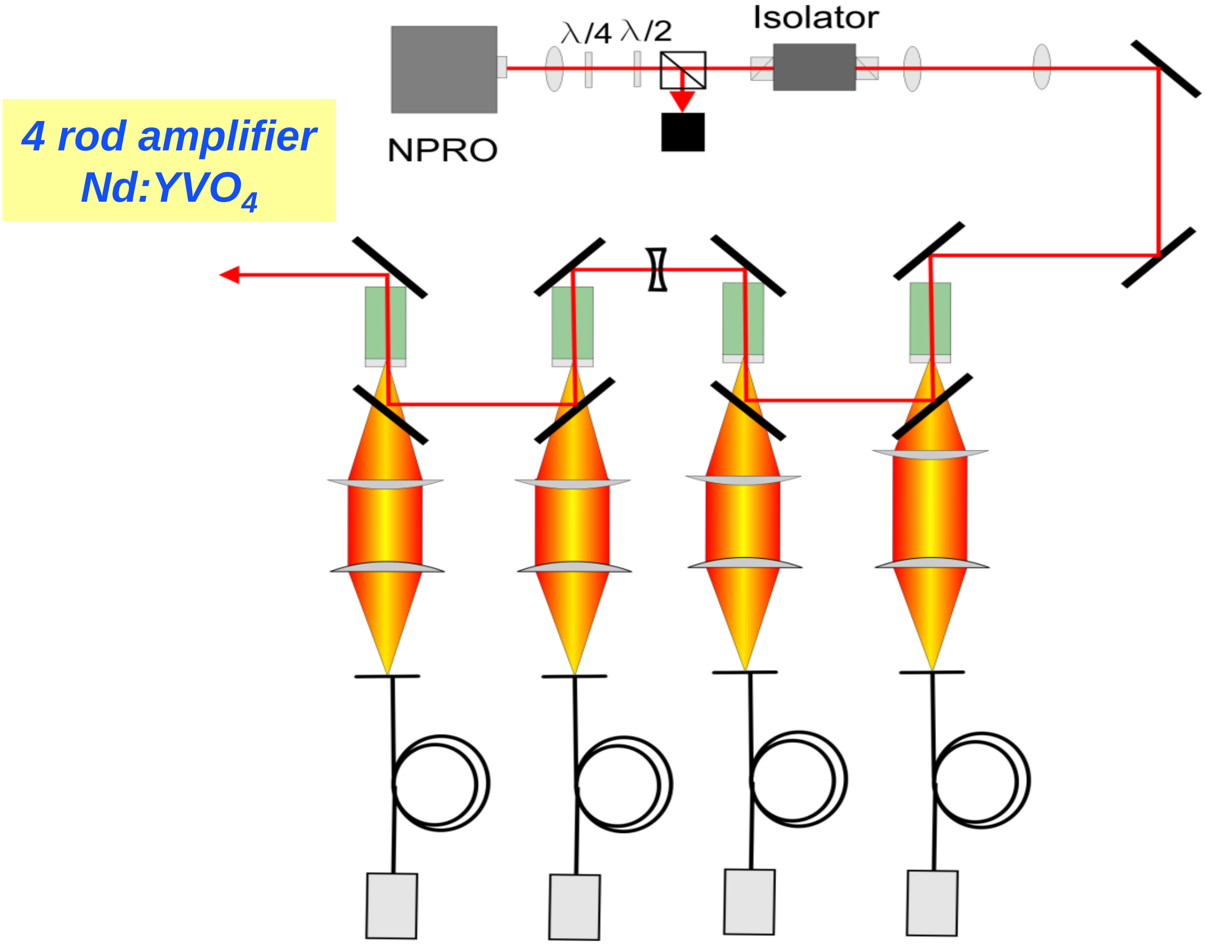
1. 30 W Laser
    1. Laser-Zentrum Hanover (LZH) AdLIGO technology
2. DC Readout
    1. In-vacuum implementation
    2. Output Mode Cleaner (OMC)
    3. AdvLIGO HAM stack
3. High Power Input Optics (Modulators / Isolators)
4. Thermal Compensation
5. Miscellaneous …

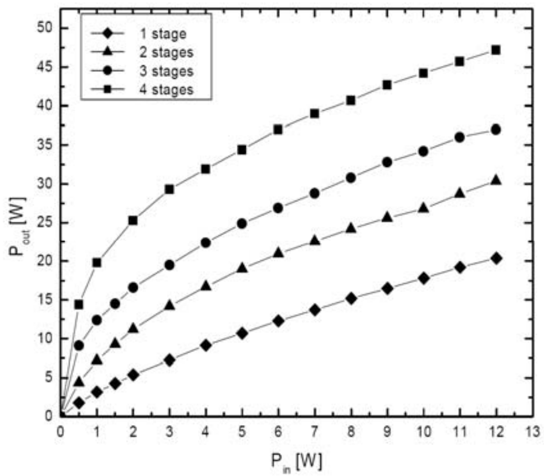
Noise sources for an enhanced detector



Higher Power Laser

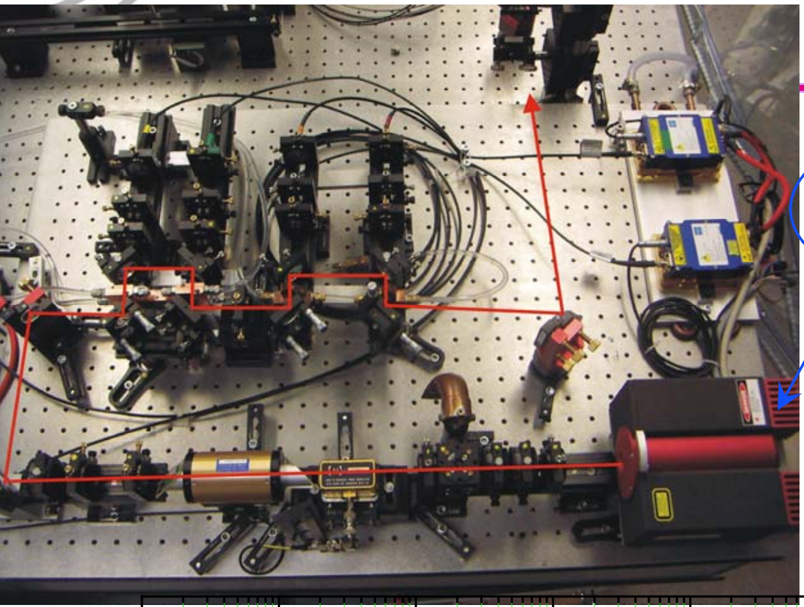
- 30W MOPA:
  - 4-rod amplifier from LZH (front-end of the AdvLIGO laser)





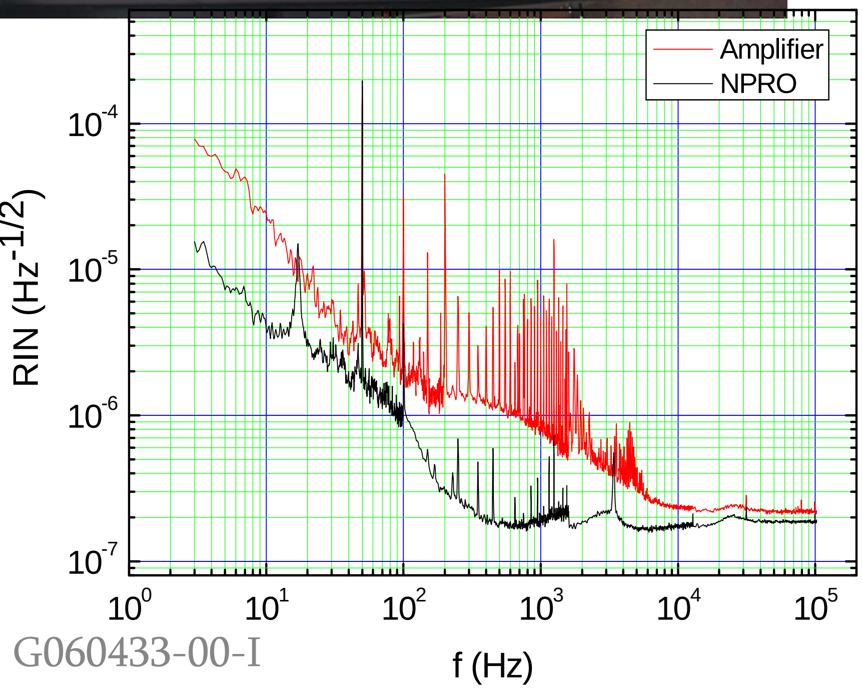
30W LZH Laser

No LWE/JDSU products included

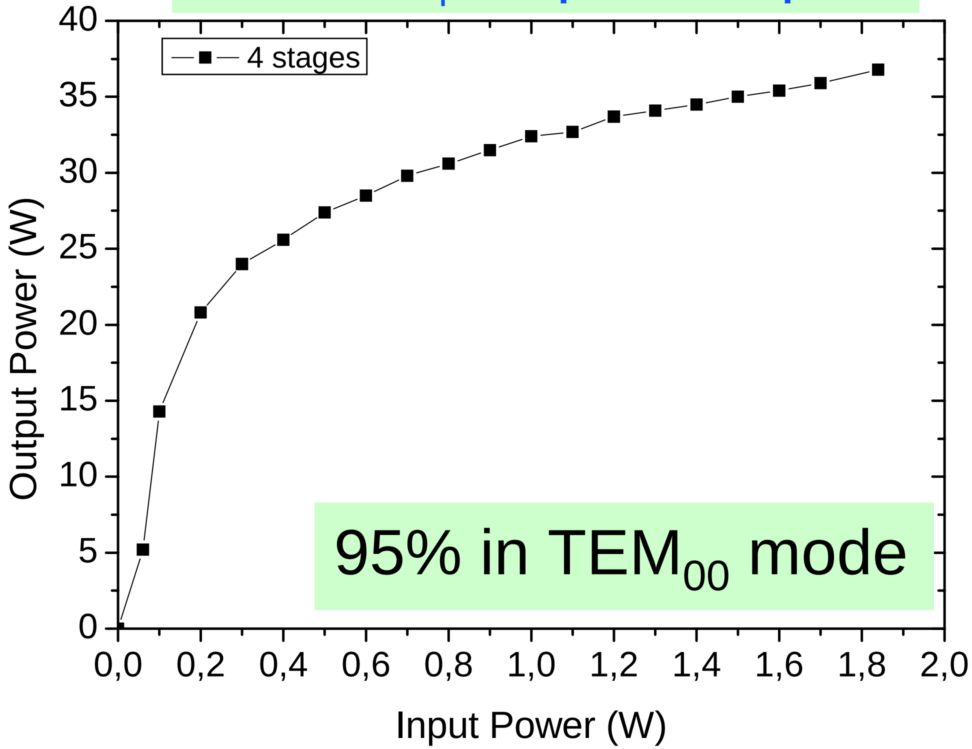


Innolight
2W NPRO

Lasers for H1 & L1
+ 1 spare offered by AEI
as their eLIGO contribution
(for free)



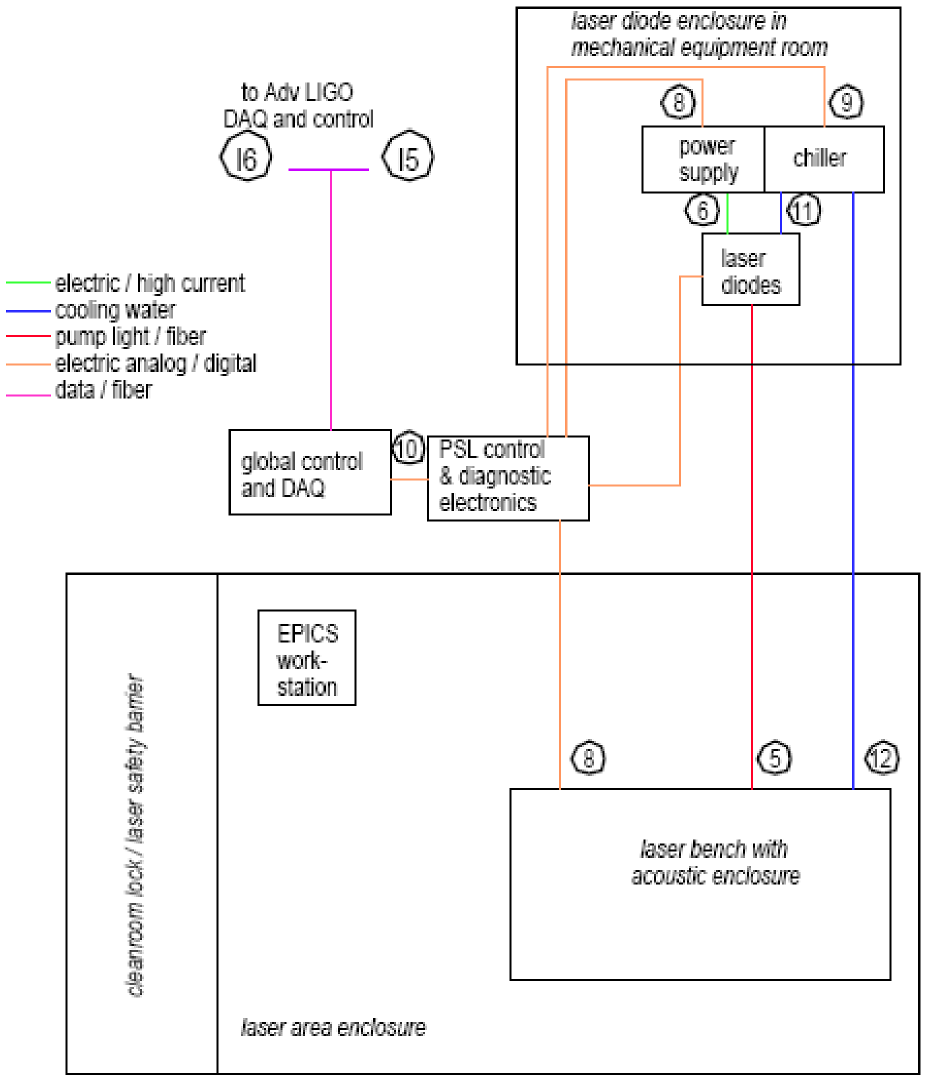
Nd:YVO_4 output v. input



95% in TEM_{00} mode

from Bastian Schulz (LZH)

Implementing the new MOPA



LIGO lab provides:

- space & enclosure in mechanical room for laser diodes
- monitor & control interfacing to laser
- phase corrector PC for FSS
- current TTFSS will work
- ISS may be done using an AOM between NPRO and MOPA (avoids long control signal cable to laser diode rack)
- Could get one MOPA early 2007: test at Caltech

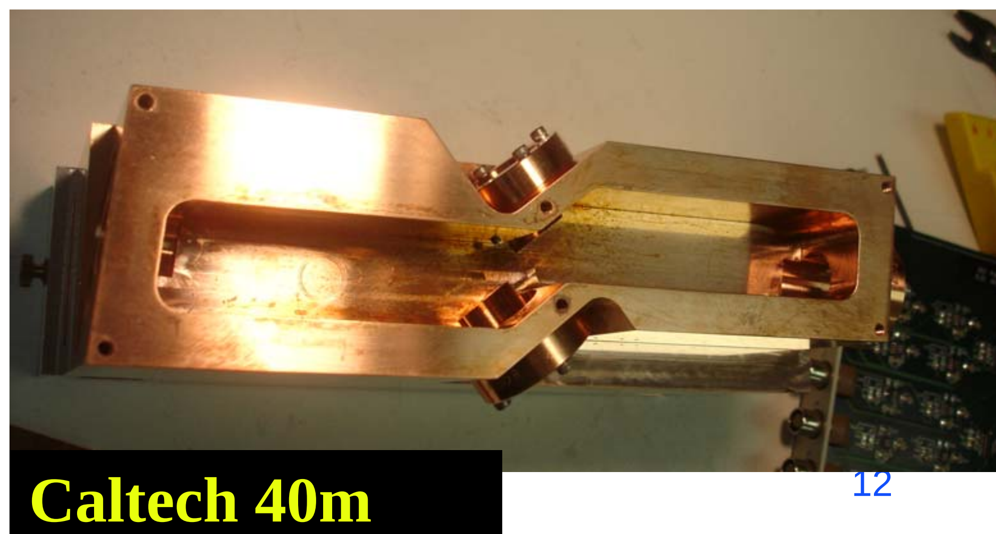
Proposed Improvements

1. High Power Laser
   1. Laser-Zentrum Hanover (LZH) AdLIGO technology
   2. Amplify existing MOPAs w/ commercial amplifiers
2. DC Readout
   1. In-vacuum implementation
   2. Output Mode Cleaner (OMC)
   3. AdvLIGO HAM stack
3. High Power Input Optics (Modulators / Isolators)
4. Thermal Compensation
5. 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:
  - Optical gain increase (field overlap)
  - 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)

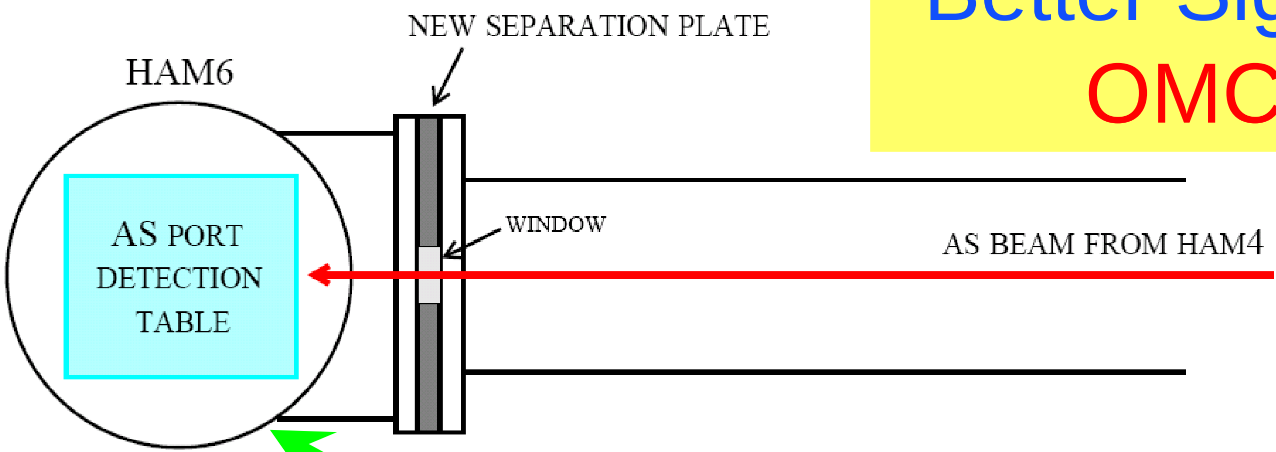


Better Signal Detection: Output Mode Cleaner

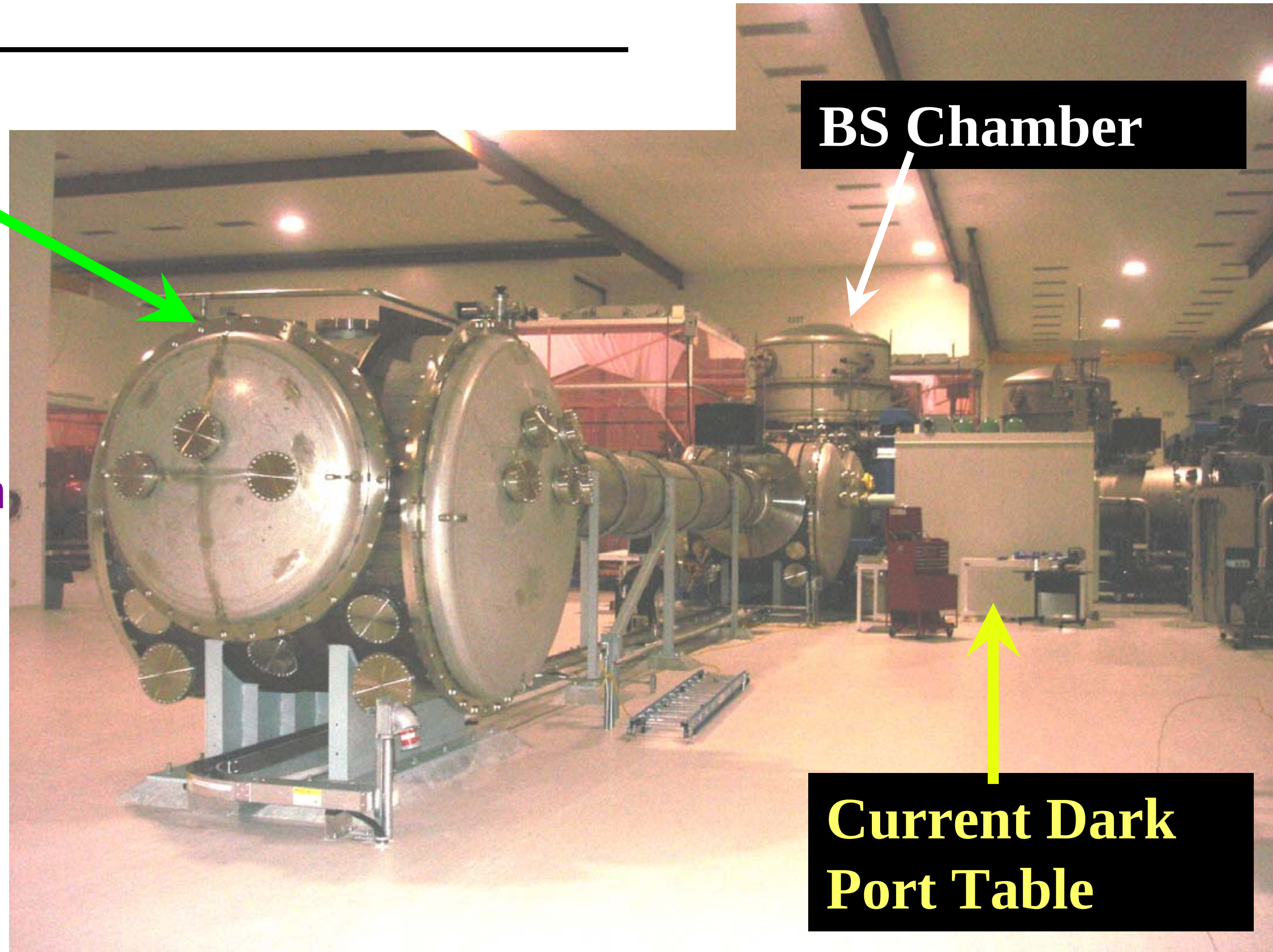
1. In-vacuum Cavity and Photodetectors*
   1. Hanford 4K experience: too much seismic/acoustic noise
   2. In an unused HAM chamber (HAM6)
   3. Baseline for AdvLIGO
2. Seismic Isolation (AdvLIGO Stack)
   1. Baseline HAM: 1 stiff internal stage + HEPI
   2. Alternative HAM: HAM-SAS (low resonant frequency)
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 system
   1. Piezo-Jena PZTs (or midi-SUS ala Ponderomotive @ MIT)
   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
- Design for easy access
- In-air commissioning in the beginning

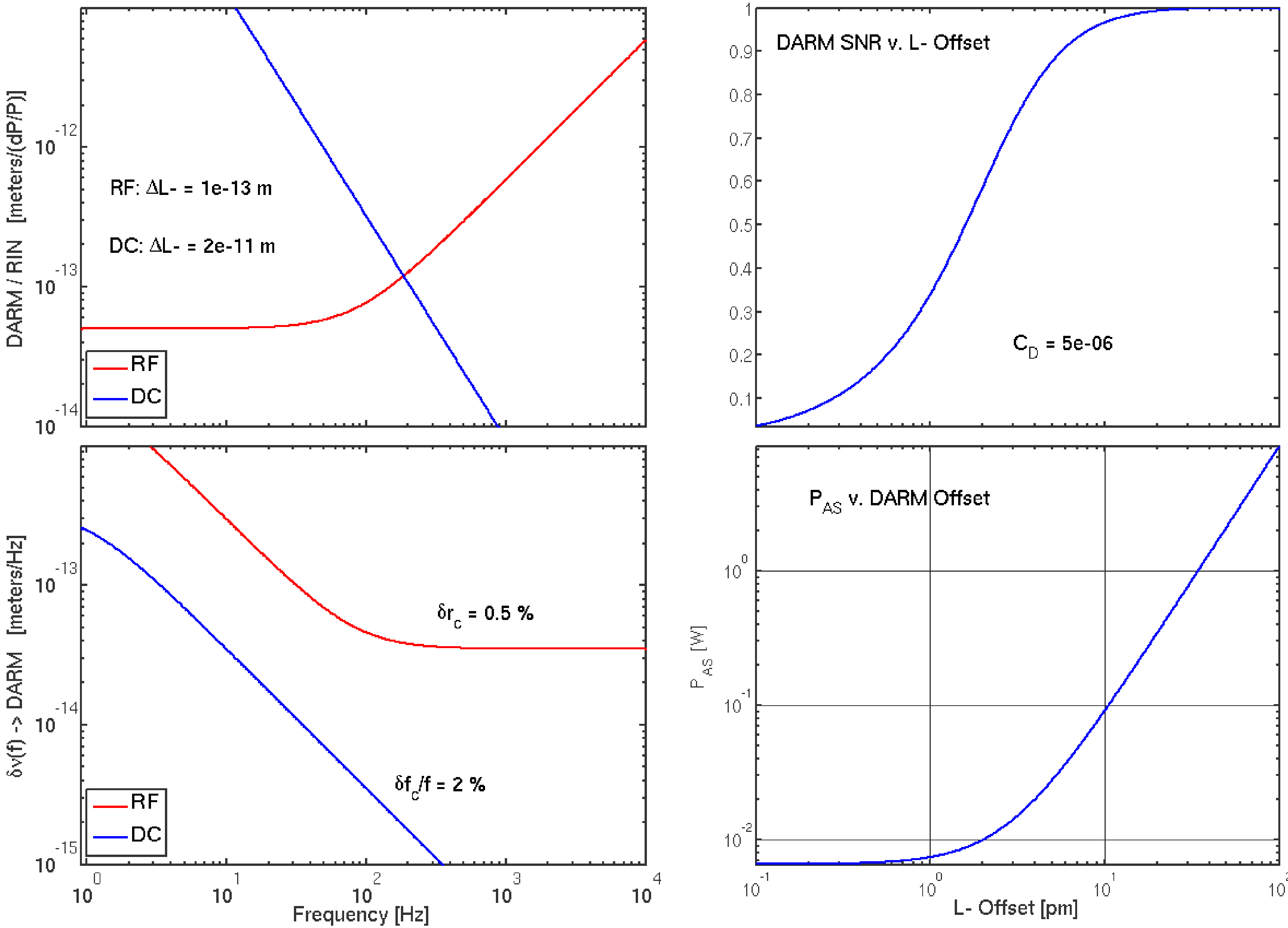


Seismic Isolation for OMC

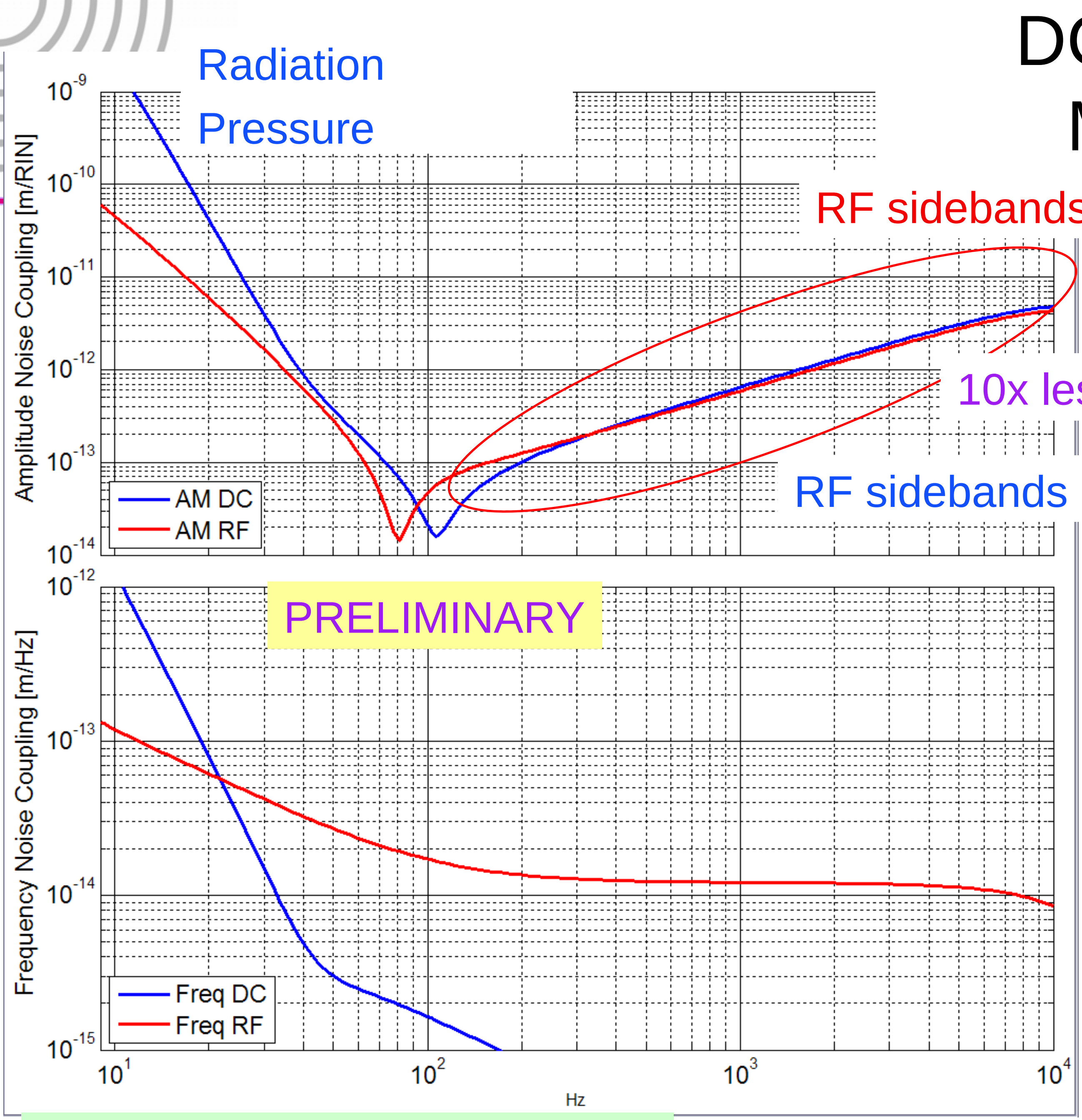
- Requirements are ‘easy’ to meet. Only need ~2 passive stages (1 double pend or a decent stack).
- Plan for the minimal suspension that might also work for AdvLIGO.

- OMC Suspension Requirements (V. Mandic + ANU)
  - Beam jitter into OMC dominated by test mass motions
  - Need a ~50 Hz BW auto-alignment servo to preserve strain noise
  - Future work: length noise requirements, design of a fast thermal actuator, HOM scattering noise modeling (need beam profiles of the real AS port beams)

DC Readout Modeling



DC Readout Modeling



L- = 10 pm

OMC F = 500

Γ_{25} = 0.3

using Matt Evans' new Optickle

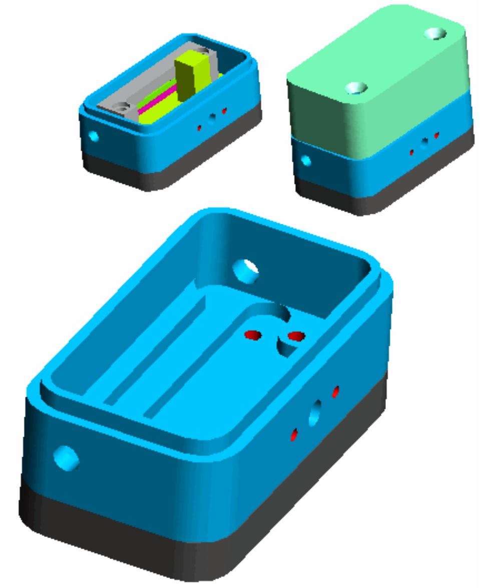
High Power Input Optics

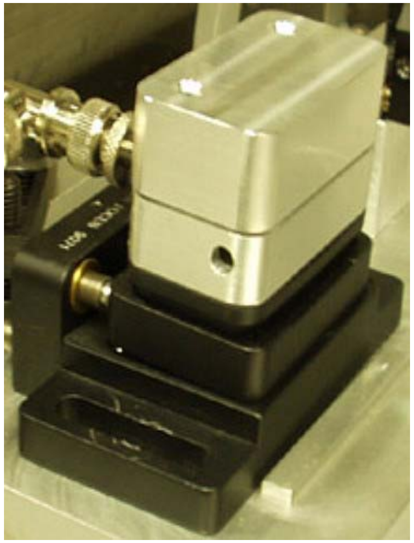
- Initial LIGO Modulators and Isolators are at their power handling limits.
- EO Modulators are being operated beyond the recommended damage threshold. Some high power ‘blooming’ damage seen at < 10 W.
- Faraday Isolators exhibit significant thermal beam steering; patched with an active beam stabilization system. There’s also poor quality of the symmetric port beam and low overall transmission efficiency.

- UF Modulators/Isolators PDR in April ‘06
  - R&D is well underway
  - U. of Florida is ready to implement their designs for Enhanced LIGO

New EOM

- RTP modulators developed by UFlorida for AdLIGO
- Thermal lensing is 30-50x smaller than in LiNbO3
- Crystals available from 2 vendors
  - 4mm x 4mm x 15mm
- Packaged by UFl in a housing similar to NewFocus

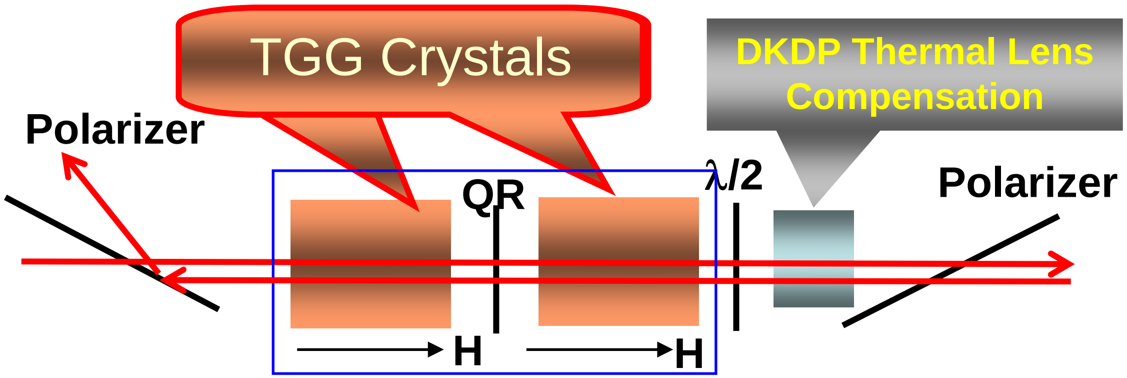




- Packaging details to be determined:
  - Electrodes: 2 independent electrodes on 1 crystal to apply multiple frequencies
  - Matching network: may house outside xtal box

New in-vacuum Faraday isolator

- Design developed by UFI for AdLIGO
  - Two 22.5° TGG-based rotators with a reciprocal 67.5° quartz rotator between
  - Polarization distortions from the first rotator compensated in the second.
  - ½ waveplate to set output polarization.
  - Thermal lens compensation *via* negative *dn/dT* material: deuterated potassium dihydrogen phosphate, KD_2PO_4, or 'DKDP').
- Polarizers:
  - Thin film polarizers: smaller thermal beam deflection than calcite
  - TFPs possibly complemented with calcite pols for better isolation
- Mounted on breadboard as single component



TCS Requirements

optic	calculated induced central heat	Req'd annulus TCS heating	Req'd CO2 power	Calc. thermolastic noise
H1 ITMX	-225 mW	2.5 W	5.8 W	3.8×10^{-19} m / $Hz^{1/2}$
H1 ITMY	-356 mW	3.9 W	9.1 W	5.9×10^{-19} m / $Hz^{1/2}$

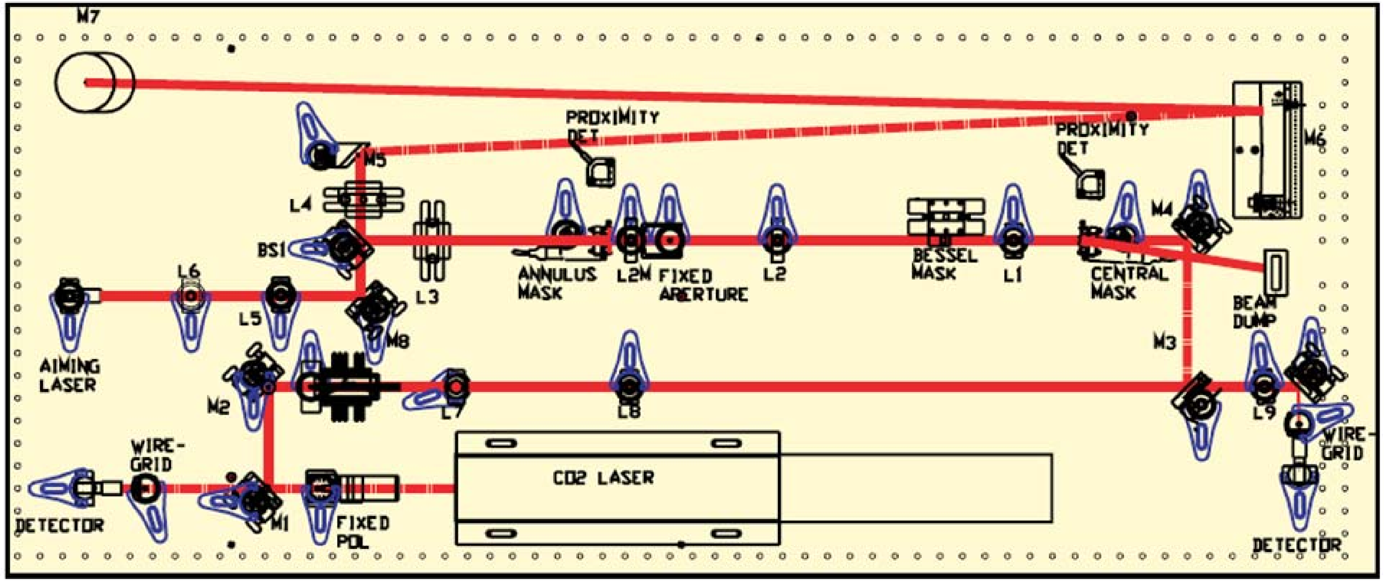
assumptions:

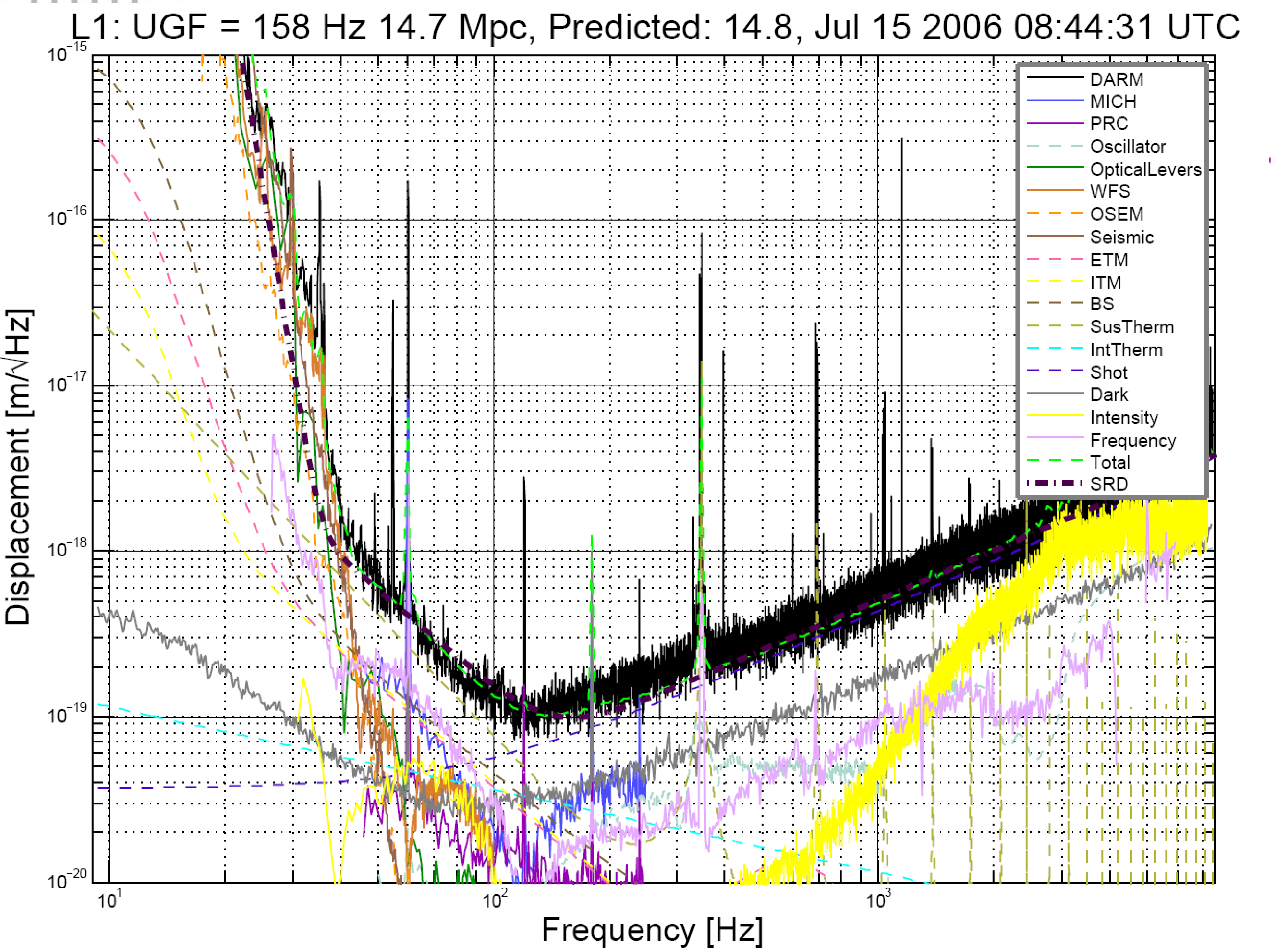
- 30 W YAG power
- Induced central heat is the equivalent TCS power
- 11 annulus W is equivalent to 1 central W induced ROC
- Thermoelastic noise at 100 Hz with 1e-5 / rtHz RIN.

WIKI: http://ilog.ligo-wa.caltech.edu:7285/advligo/Thermal_Compensation_for_mLIGO

TCS Development

- 20 W CO_2 lasers are available with poor RIN ~ 10^{-5}
- In use photovoltaics can achieve RIN > 10^{-7} -- not good enough
- Large signal PVs plus AOM "peak shaving" can achieve RIN ~ 3 x 10^{-8} (see note by RW in WIKI)
- Retain current TCS optical bench (replace annulus mask with axicons?)

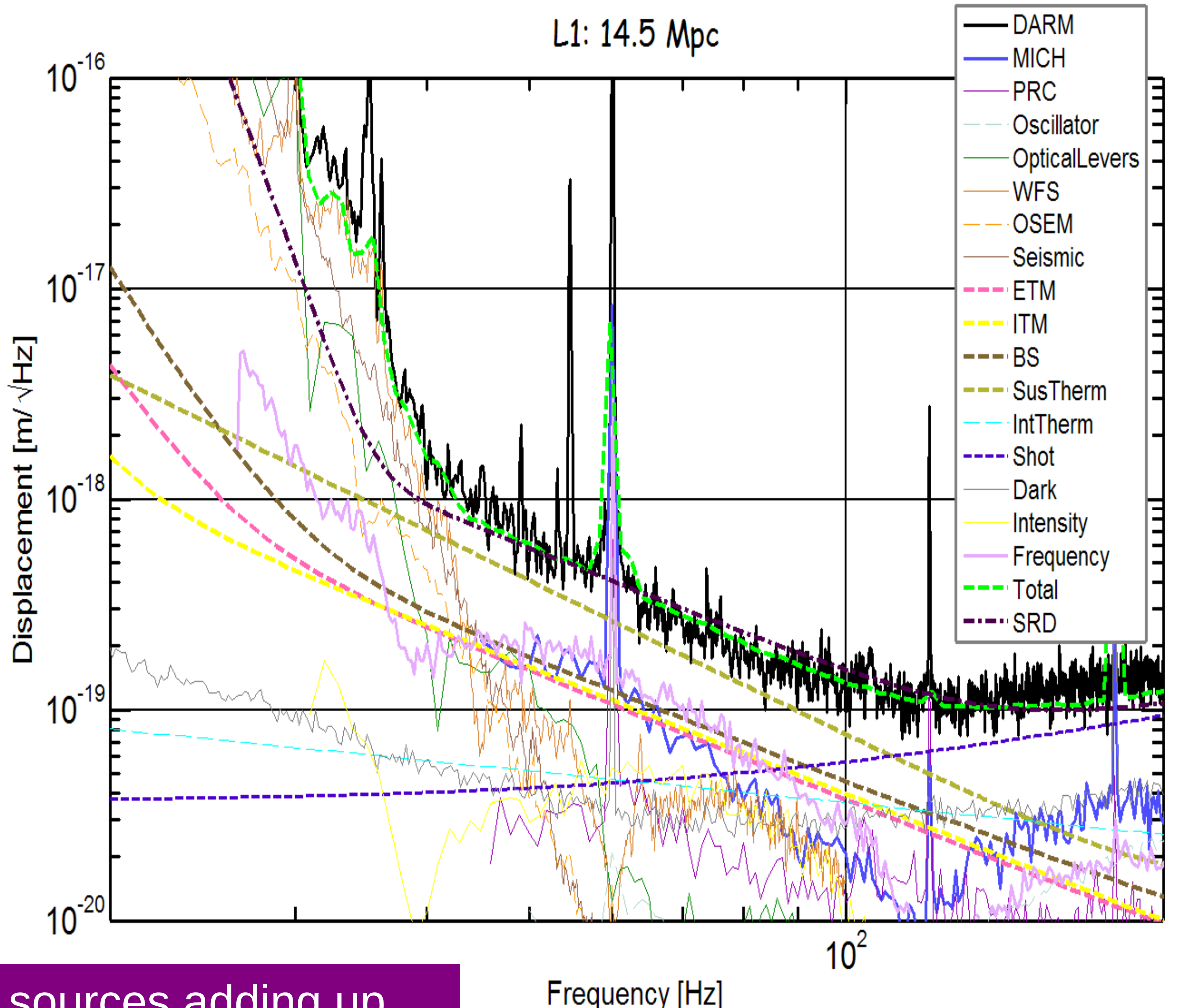




L1: UGF = 158 Hz 14.7 Mpc, Predicted: 14.8, Jul 15 2006 08:44:31 UTC
Displacement [m/√Hz]
Frequency [Hz]
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

Suspension Electronics

- ❑ Noise:
  - ➢ Bias Modules (noisy, small resistors)
  - ➢ Coil Drivers (bigger resistor, different filter)
- ❑ Fixes:
  - ➢ Weiss Bias Modules
  - ➢ Test mass realignments (+/-10 urad)

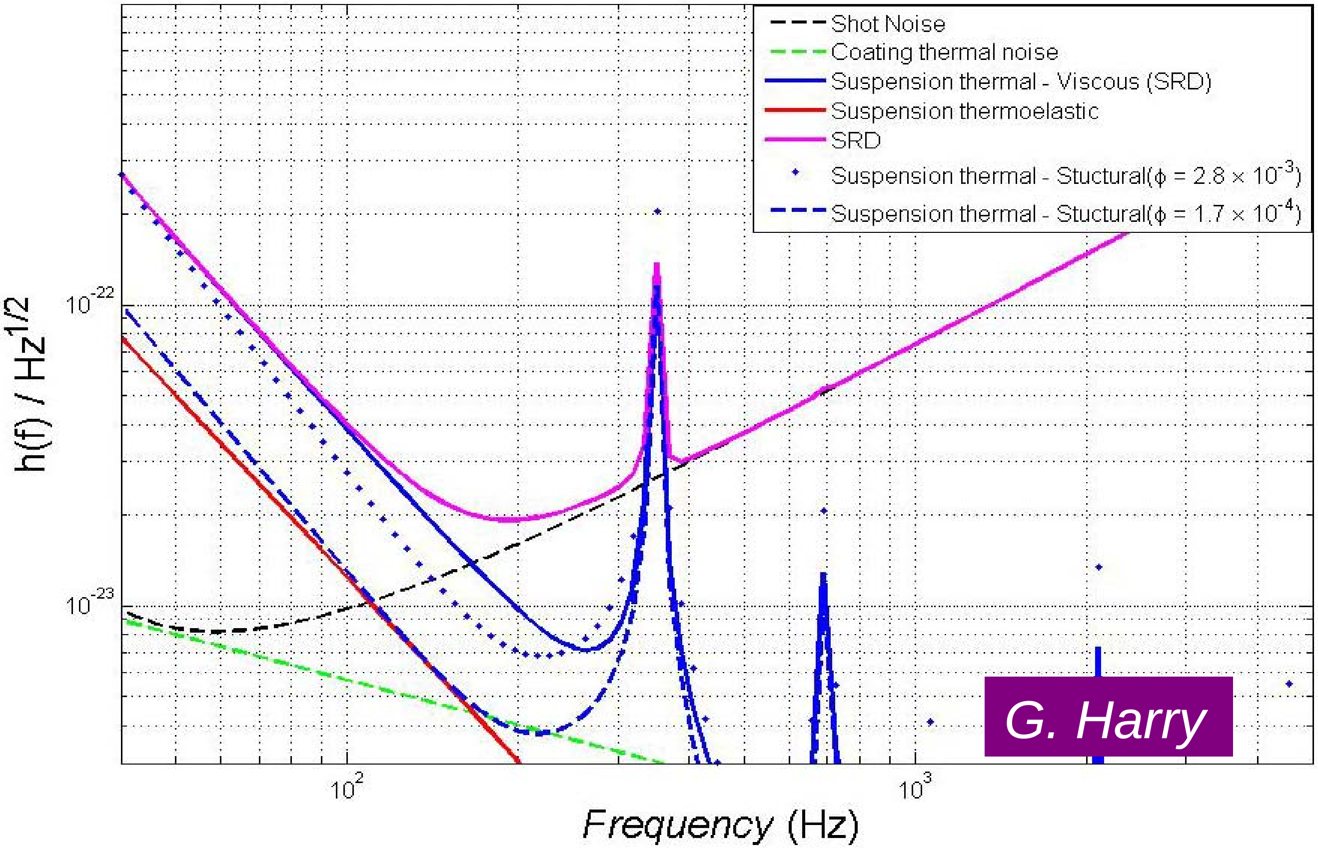


Many noise sources adding up

Suspension Thermal Noise

- Structural loss limited noise is ~3x less than SRD. Best L1 curve limits the loss to less than 1e-3.

- R&D (Penn,Harry):
  - iLIGO-like wire suspension measurements
  - Excess loss studies (e.g. clamps)
- Payoff:
  - Sensitivity improvement in the most sensitive band.

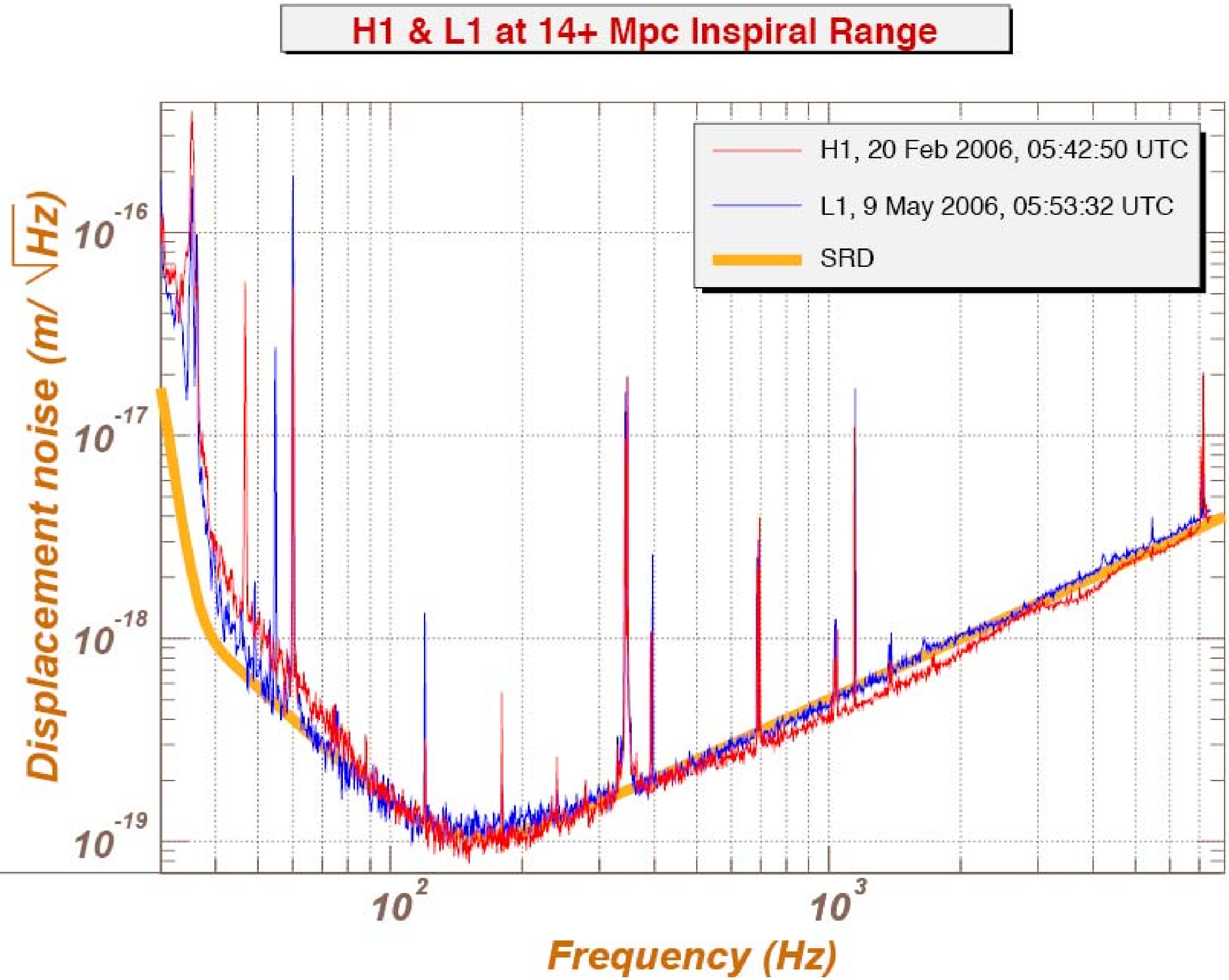


LIGO "Mystery" noise

Correlation between 40-200 Hz DARM and <10 Hz seismic noise

Significant effect on inspiral range from Hanford HVAC modulation

"Baseline" 40 - 120 Hz noise unexplained by Noise Budget



Mystery Mechanisms

- Violin-mode Q measurements consistent w/ low wire loss and low thermal noise *but not all wires tested and clamp stick/slip may be an issue in the future*
- Optic motion alone insufficient to increase noise from free swinging CARM measurement
- Low F up-conversion caused by actuation force alone unrelated to suspension stack
- Actuation chain electronics are the probable cause for Low F up-conversion - “easily” fixable
- Optical scattering probably not the dominant up-conversion mechanism b/c of incompatible spectra
- Retraction of the earth quake stops from LLO ITMY greatly reduced “baseline” noise - could be applied to all IFOs
- HVAC up-conversion noise effect still unexplained

Outlook

- **Lots of design, development, procurement (now ->7/07)**
- 2 years of installation and commissioning (until Fall of 2009)
- 18 months for S6 (Fall 09 -> early 2011) @ LLO
- Cost: ~1.5 M$
- Enhancement: ~2X in NS range for H1/L1

End / Todo:

- Laser
  - Get data from LZH.
  - Schedule testing and servo development.
- DC Readout
  - Flesh out the 40m DC readout plans (what tests do we need?).
  - Continue the OMC design study.
  - More optical modeling
  - Wait for the HAM selection process.
- IOO – new drawings (REFL/ISS pickoffs)
- Sus Elec – develop and review new Bias circuit
- Sus Therm – continue the MIT R&D
- Upconversion
  - This is a critical unknown. Need to take some time out of the run; so far compatible with the 25 hr monthly commissioning budget.