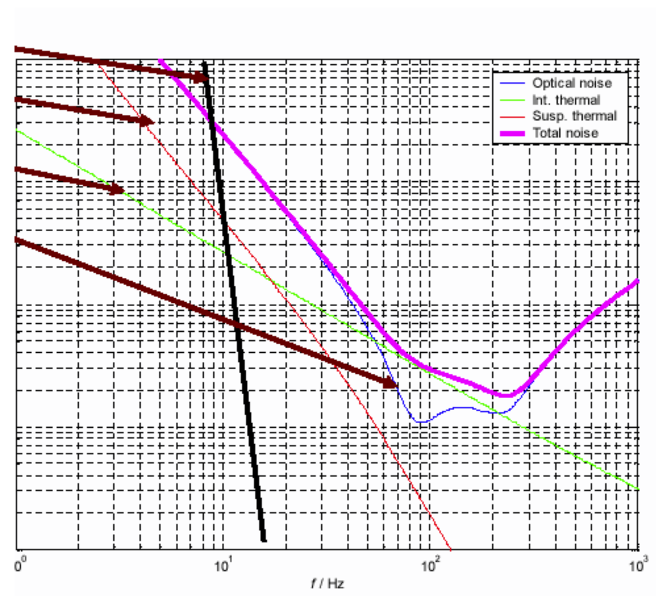
Caltech 40 meter Prototype Program

- Objectives
- Accomplishments in the last year
  - » Infrastructure
  - » IFO planning
  - » modeling
- Goals for the coming year: infrastructure and IFO
- Schedule through 2004
- Personnel and LSC involvement

40m Laboratory Upgrade - Objectives

- Primary objective: full engineering prototype of optics control scheme for a dual recycling suspended mass IFO
  - » Table-top IFOs at Caltech, Florida, Australia, Japan (~ complete!)
  - » These lead to decision on control scheme by LSC/AIC (August 2000 LSC)
  - » Then, Glasgow 10m does a “quick” test of the scheme
  - » Then, full LIGO engineering prototype of ISC, CDS at 40m
  - » First look at DR shot noise response (*high-f*)

- Other key elements of LIGO II are prototyped elsewhere:
  - »**LASTI, MIT**: full-scale prototyping of Adv.LIGO SEI, SUS (*low-f*)
  - »**TNI, Caltech** : measure thermal noise in Adv.LIGO test masses (*mid-f*)
  - »**ETF, Stanford:** advanced IFO configs (Sagnac), lasers, etc



Need for prototyping

- The Advanced LIGO optical configuration and control scheme is *extremely* complex, with many innovations.
- Without a high-fidelity prototype of the system, it would take *years* to make the transition from Initial -> Advanced LIGO (mistake learned the hard way during Initial LIGO commissioning).
- LIGO observatories must remain undisturbed during initial science run, and transition between Initial -> Advanced LIGO must proceed as quickly and efficiently as possible
- Full engineering prototype is essential for minimizing downtime between Initial -> Advanced LIGO; prototyping pays for itself.
- The Glasgow 10m IFO will test many elements of the optical and control scheme, but will be very limited, and will not reduce the technical risk. Its primary goal is to provide input to the the 40m experiment (K. Strain, LSC AIC chair, Glasgow).

Advanced LIGO technical innovations tested at 40m

- a seventh mirror for signal recycling
  - » (length control goes from 4x4 to 5x5 MIMO)
- detuned signal cavity (carrier off resonance)
- pair of phase-modulated RF sidebands
  - » frequencies made as low and as high as is practically possible
  - » unbalanced: only one sideband in a pair is used
  - » double demodulation to produce error signals
- short output mode cleaner
  - » filter out all RF sidebands and higher-order transverse modes
- offset-locked arms
  - » controlled amount of arm-filtered carrier light exits dark port of BS
- DC readout of the gravitational wave signal

Much effort to ensure high fidelity between 40m and Adv.LIGO!

40m Laboratory Upgrade – More Objectives

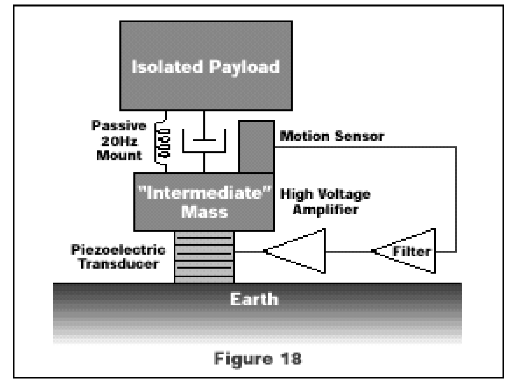
- Expose shot noise curve, dip at tuned frequency
- Multiple pendulum suspensions
  - » this may be necessary, to extrapolate experience gained at 40m on control of optics, to LIGO-II
  - » For testing of mult-suspension controllers, mult-suspension mechanical prototypes, interaction with control system
  - » Not full scale. Insufficient head room in chambers.
  - » Won't replace full-scale LASTI tests.
- thermal noise measurements
  - » Mirror Brownian noise will dominate above 100 Hz.
- Facility for testing/staging small LIGO innovations
- Hands-on training of new IFO physicists!
- Public tours (SURF/REU students, DNC media, princes, etc)

Accomplishments in last year: Infrastructure

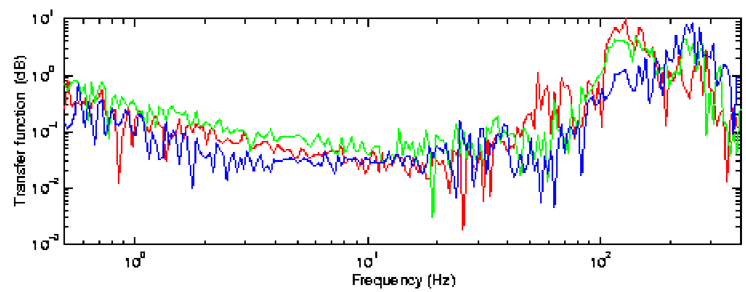
- Dismantling of old IFO, distribution of surplus equipment to LIGO and LSC colleagues
- Major building rehab:
  - » IFO hall enlarged for optics tables and electronics racks
  - » roof repaired, leaks sealed
  - » new electrical feeds and conditioners, 12" cable trays, etc
  - » new control room and physicist work/lab space
  - » New entrance room/changing area
  - » rehab of cranes, safety equipment, etc
- Active seismic isolation system (STACIS) procured, installed, and commissioned on all four test mass chambers

LIGO

STACIS Active seismic isolation



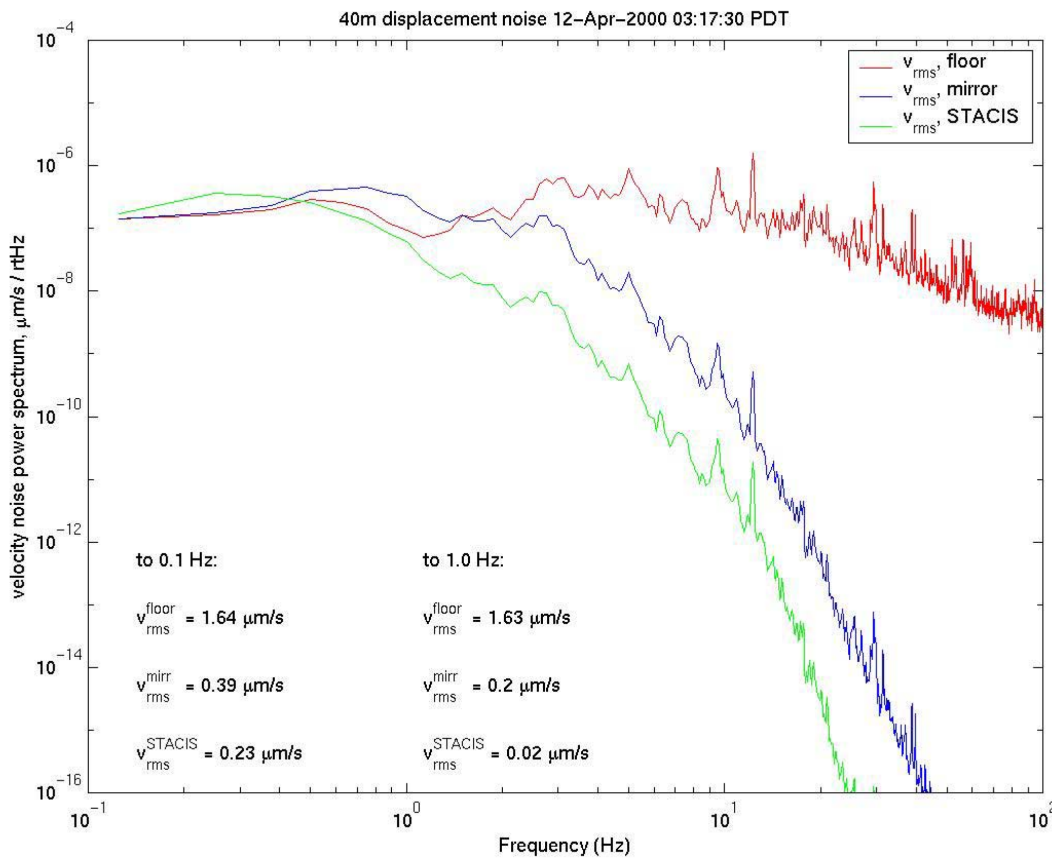
- One set of 3 for each of 4 test chambers
- 6-dof stiff PZT stack
- Active bandwidth of 0.3-100 Hz, 20-30dB of isolation
- passive isolation above 15 Hz.



Noise spectrum, floor+stacks+pendulum+STACIS

Conclusions depend critically on whether one includes 0.1-1.0 Hz, where:

- STACIS transfer function is not well known;
- ground motion is not well measured;
- relevance to control system, MMT, is not clear to me!



Accomplishments in last year: Infrastructure, continued

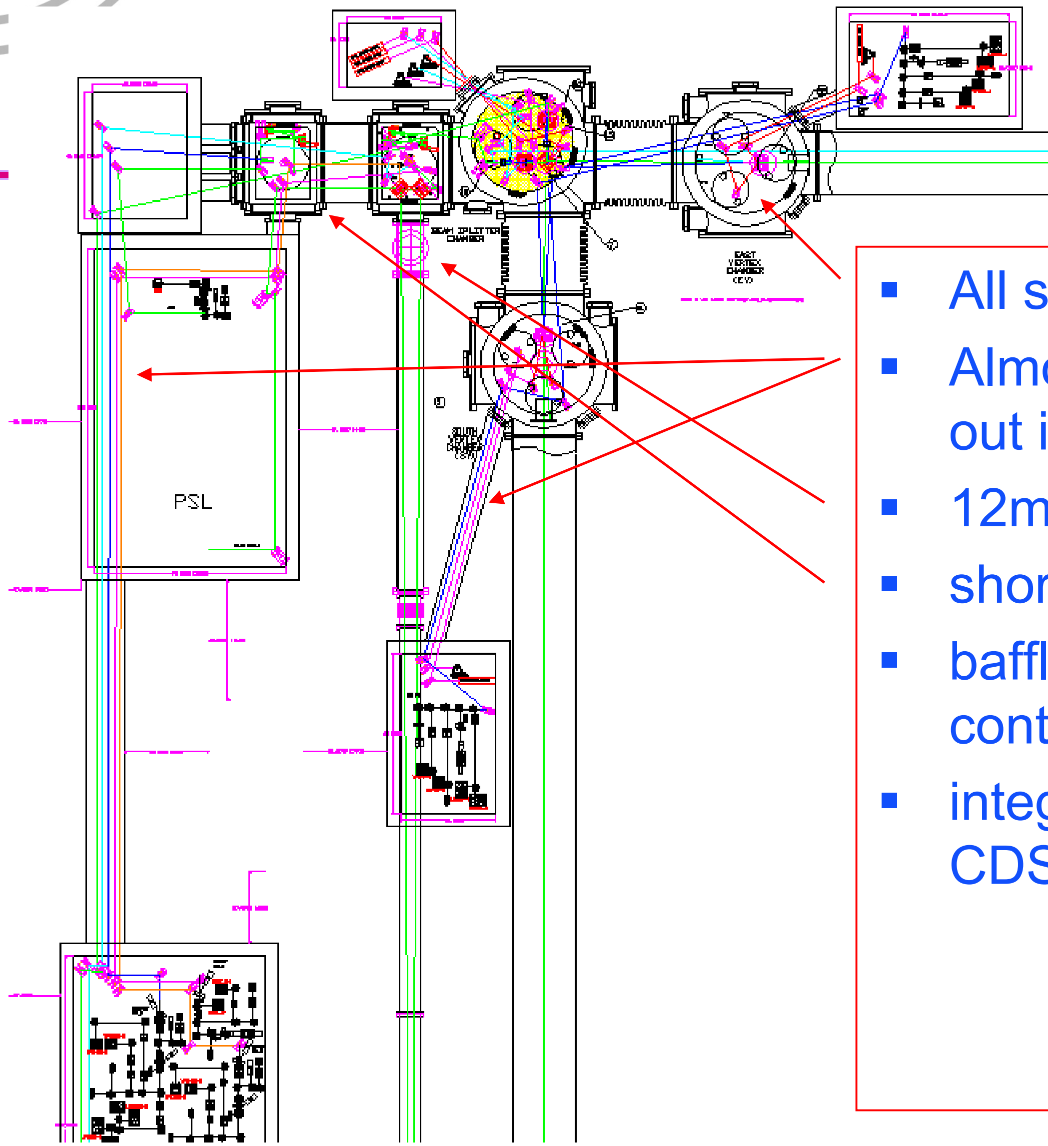
- New vacuum control system and vacuum equipment
- New output optic chamber, seismic stack fabricated
- Vacuum envelope for 12 m input mode cleaner fabricated
- Electronics racks, crates, computers, network… procured

All the above will be installed and commissioned in the coming months!

Accomplishments in last year: IFO planning

- Initial-LIGO-like PSL being assembled; installation begins in February
- New 12 meter input mode cleaner design finalized; vacuum envelope assembly beginning in February
- Detailed optical layout in advanced stages
  - » all in-vacuum components laid out
  - » optical levers for all suspended masses
  - » baffling, scattered light suppression, shutters, etc
  - » Nine output beams routed to optical tables near electronics racks
  - » input mode cleaner, output mode cleaner, mode-matching telescopes laid out
  - » integrated with building, electrical, CDS layout
- Suspended optic glass blanks on order
- Initial-LIGO SOS suspensions for MC, BS, RM, SM under construction
- Scaled SOS suspensions for ITMs, ETMs under design
- Detailed WBS for construction
- Detailed WBS for experiment is in progress

Optical Layout

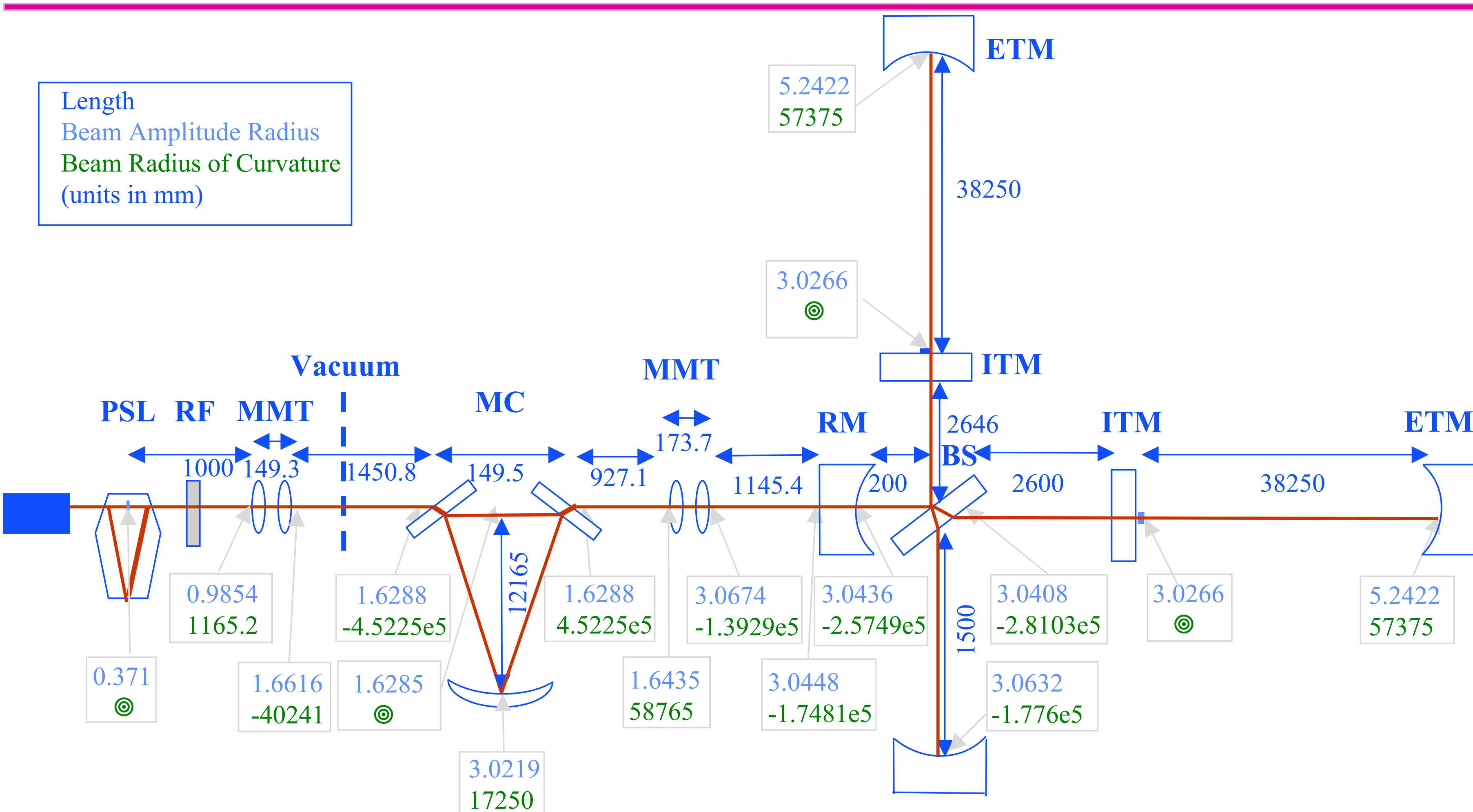


- All suspended optics have OpLevs
- Almost all of 9 output beams come out in this area
- 12m input mode cleaner
- short monolithic output MC
- baffling, shutters, scattered light control
- integrated with building, electrical, CDS layout

Accomplishments in last year: Modeling

- Specification of all optical parameters
  - » Cavity lengths, RF sideband frequencies and resonance conditions
  - » mirror trans., dimensions, ROC, optical quality, tolerances…
- Detailed length-control model scheme using Twiddle
  - » Adv.LIGO and 40m following parallel paths
- Alignment sensing & control modeled using ModalModel (SURF student; requires updating)
- Suspensions for 5" test masses modeled using Simulink (SURF student)
- Noise in GW channel modeled in Matlab
- Model of IFO DC response with imperfect optics in progress using FFT program (CSUDH group)
- Model of lock acquisition dynamics using E2E in progress

Optics Parameters (flat ITMs)



Length sensing signals from Twiddle

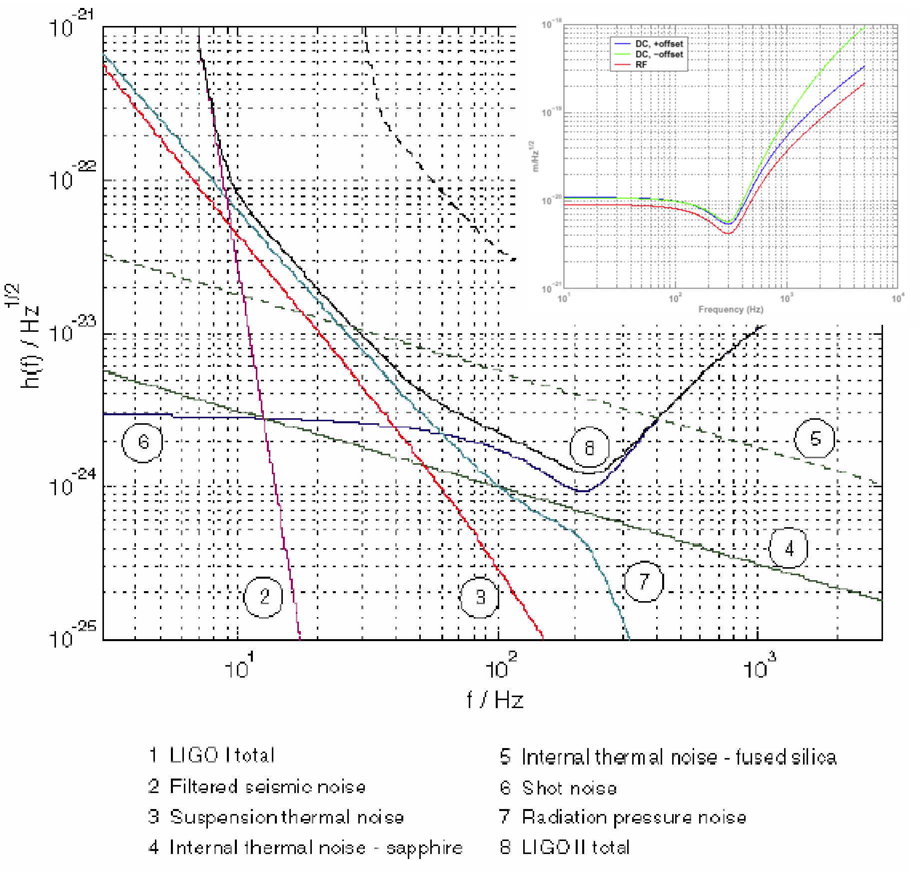
Table 4: LSC signals. $\otimes$ means double demodulation.

Signal	L_+	L_-	l_+	l_-	l_s
SP, f_1	**18.4**	0.01	-0.03	0.12	0.006
AP, f_2	0	**-42.8**	0	-0.05	0
SP, $f_2 - f_1$	0.004	0.002	**-0.155**	0.045	0.088
AP, $f_2 \otimes f_1$	0.0001	0.0002	0.0002	**0.0036**	-0.0019
PO, $f_2 - f_1$	-0.041	0.012	-0.363	0.225	**1.22**

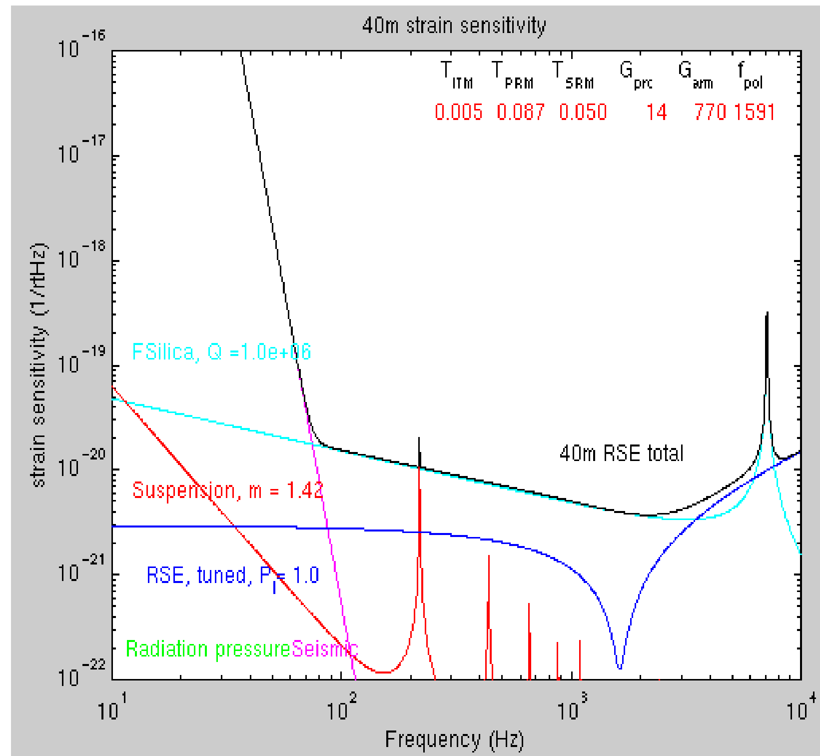
- Much more diagonal than LIGO I!
- These numbers vary as one varies arm length, unmatched arms, imperfections, losses, etc.
- l+ and l- signals are not very robust, but neither are they at LIGO I.
- PO signal must be multiplied by PO power reflectance (600 ppm nominal); is the signal big enough to be significantly above PD noise? Can make it bigger, with some sacrifice in GW shot noise response; maybe that's appropriate here. Ditto, for modulation depth.
- Double demodulation is difficult; hard to determine demod phases.
- Thanks to Jim Mason for all his help!

LIGO II and 40m noise curves

LIGO II



40m



Goals for the coming year

- Infrastructure:
  - » Return to clean-room conditions after building rehab
  - » Install output optic chamber and seismic isolation stack
  - » Install input mode cleaner vacuum envelope
  - » Fully commission vacuum control system and all new hardware
  - » Install new optical tables and associated hardware
  - » Fully commission computing and networking infrastructure
  - » Assemble PEM system and DAQS, begin regular monitoring
- IFO:
  - » Install and commission PSL
  - » Begin installation and commissioning of 12m input mode cleaner
  - » Search out environmental noise sources

Milestones through 2004

- 4Q 2001: Infrastructure complete
  - » PSL, 12m MC, vacuum controls, DAQS, PEM
- 4Q 2002:
  - » Core optics and suspensions ready. Suspension controllers. Some ISC.
  - » Glasgow 10m experiment informs 40m program
  - » Control system finalized
- 2Q 2003:
  - » auxiliary optics, IFO sensing and control systems assembled
- 3Q 2003: Core subsystems commissioned, begin experiments
  - » Lock acquisition with all 5 length dof's, 2x6 angular dof's
  - » measure transfer functions, noise
  - » Inform CDS of required modifications
- 3Q 2004: Next round of experiments.
  - » DC readout. Multiple pendulum suspensions?
  - » Final report to LIGO Lab.

40m Lab Staff

- Alan Weinstein, project leader
- Dennis Ugolini, postdoc
- Steve Vass, Master tech and lab manager
- Ben Abbott, technician
- Advanced LIGO engineers: Rick Karwoski, Jay Heefner, Garilynn Billingsley, Janeen Romie, Mike Smith, Fred Asiri, Dennis Coyne, Tom Frey, Peter King, etc.
- Guillaume Michel, visiting grad student (winter/spring 2001)
- Summer 2000: five SURF undergraduates

LSC involvement

- At March 2001 LSC meeting, we will issue a CALL FOR INTEREST in forming an Advanced LIGO Optical Control Configuration experimental group focused on the prototyping activities at the 40m.
- There will be many meaty tasks ripe for LSC involvement.
- A draft Conceptual Design Document will be available for review by that time.
- We expect that the Optical Control Configuration will evolve and maybe depart from the scheme outlined at the August 2000 LSC meeting; we must remain flexible for as long as possible to ensure high fidelity between the 40m prototype and what will be realized in Advanced LIGO!