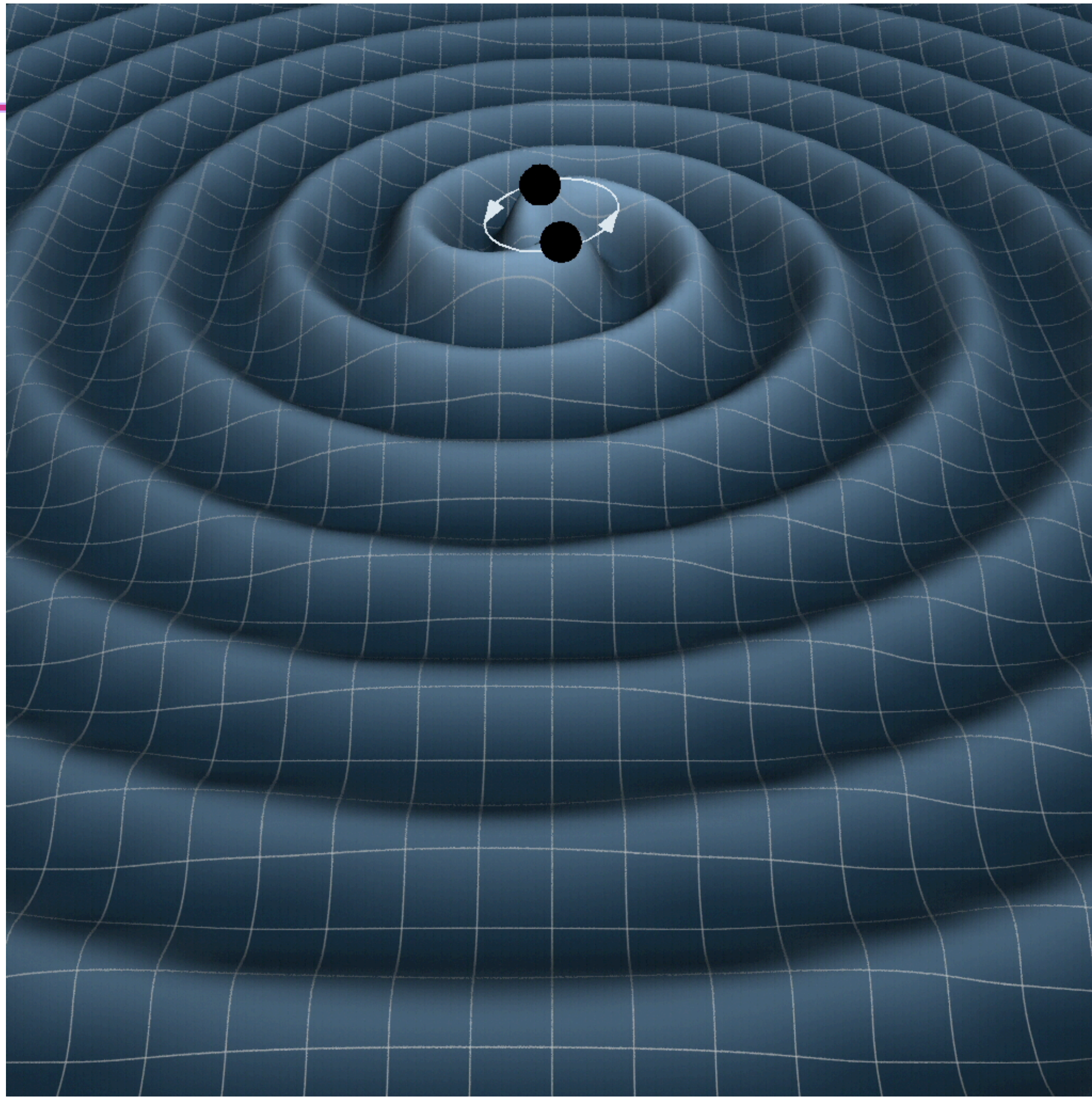
LIGO Gravitational Wave Detector: Overview & EMI Upgrade Issues

Michael E. Zucker
LIGO Laboratory, MIT

LIGO-G020296-00-D

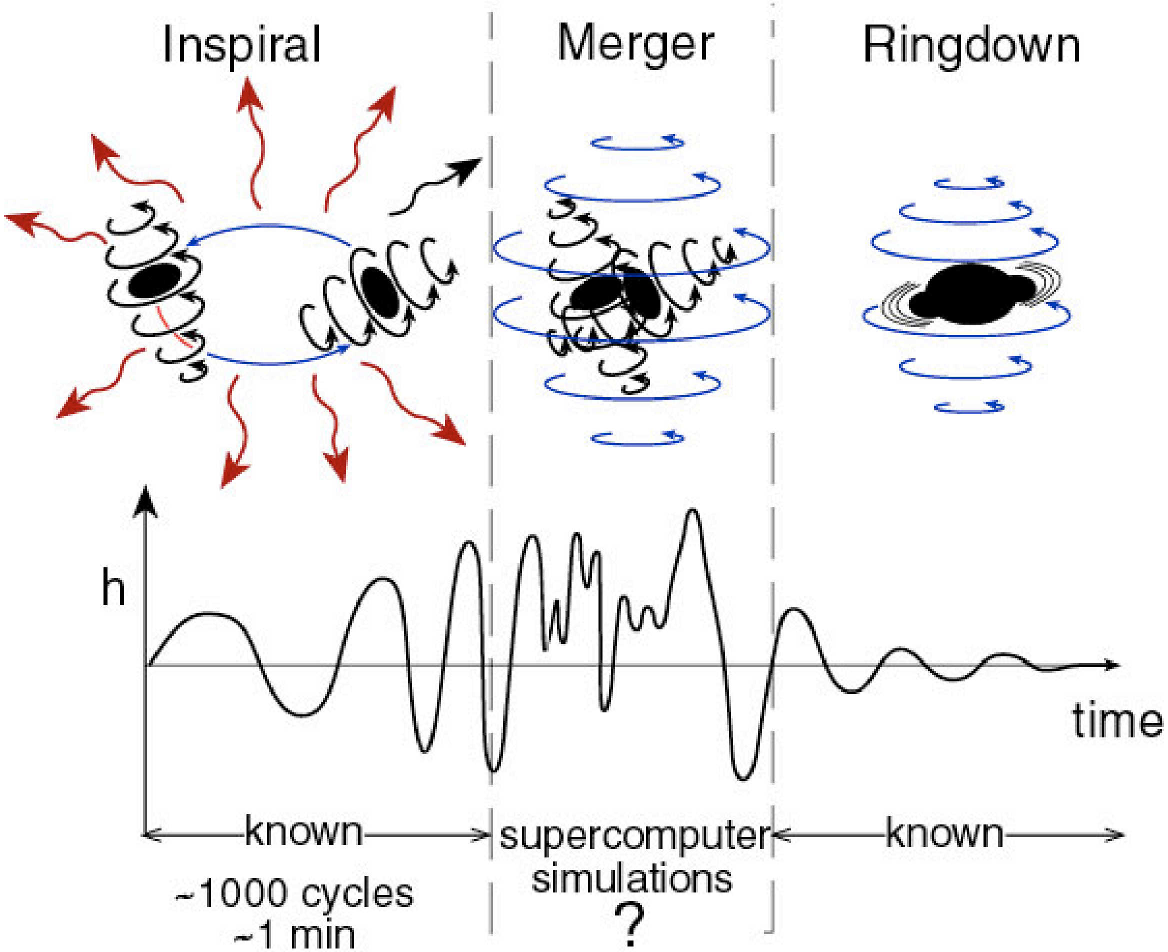
Gravitational Waves



K. Thorne (Caltech) , T. Carnahan (NASA GSFC)

- *Finite speed of information* requires a change in mass arrangement to propagate to distant observer as waves; *ripples in spacetime*
- Unlike EM waves, there's only one kind of "charge" (mass) so lowest radiating order is *quadrupole*
- Qualitatively different from other radiations; expose dynamic accelerations of mass, not atomic, thermal or plasma physics of object surfaces
- Universe and matter mostly transparent to gravitational waves; nothing can be hidden

Example: BH/BH Mergers



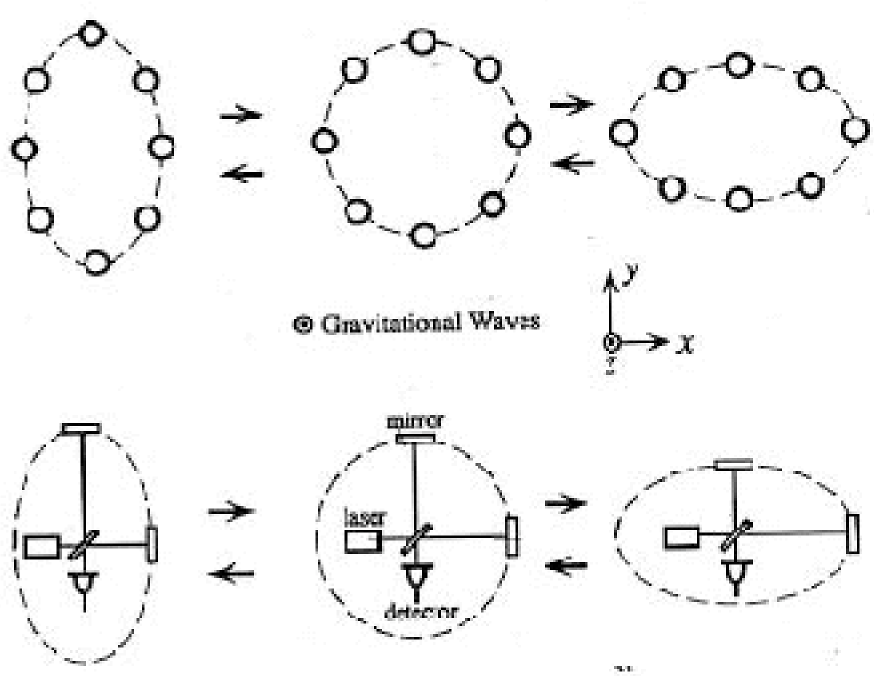
GW's are predicted from various classes of compact objects we know of indirectly, by other means,

BUT

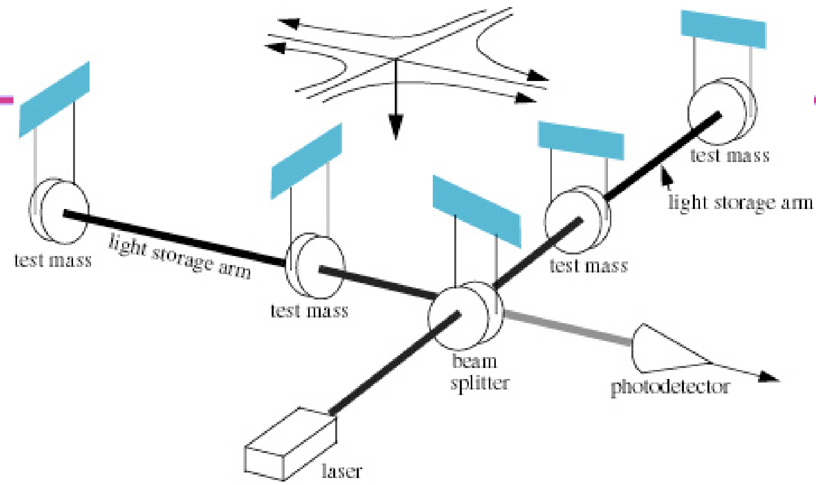
The most prominent sources may well turn out to be *unpredicted* from what is known by other methods

(examples of early radio and X/gamma ray astronomy bear witness!)

Wave effect on inertial test particles



Interferometer Detectors



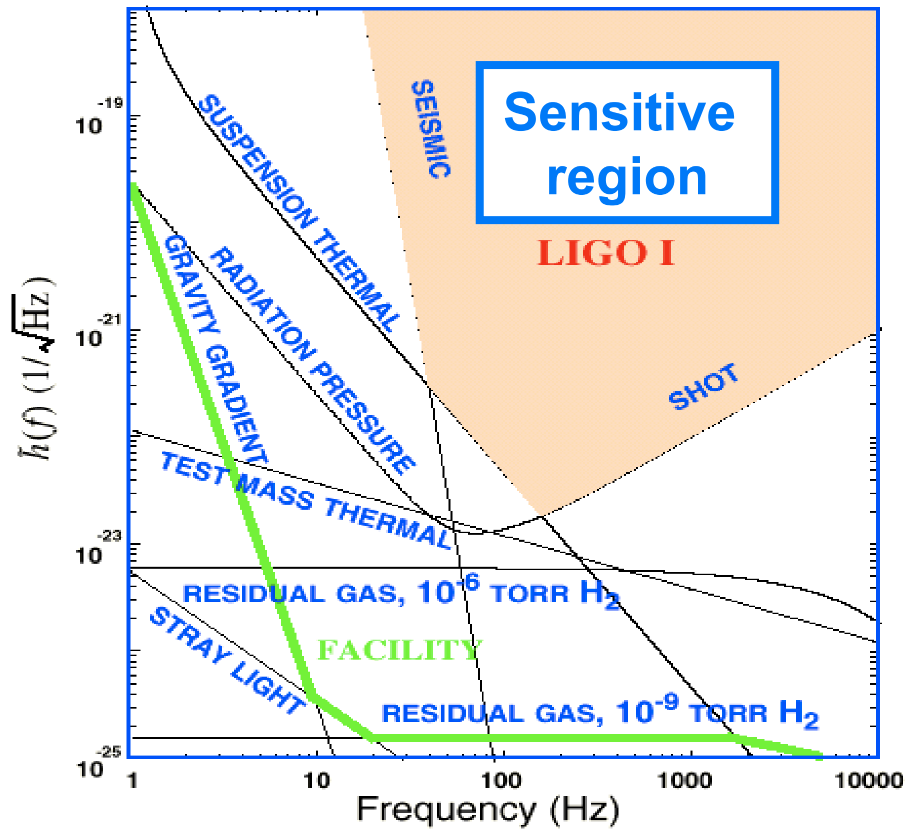
- **Michelson-type interferometer compares orthogonal geodesics**
  - **Concept of interferometer as GW detector proposed as early as '52**
  - **Weiss ('72) made first serious design and sensitivity analysis**
  - **Many enhancements, but primary features and limitations identified then still apply**
- **PROBLEM: waves are *weak*, e.g., for binary ns inspiral calculate**

$$|h| \approx 4\pi^2 GMR^2 f_{orbit}^2 / c^4 r \approx 10^{-21} \left(\frac{R}{20\text{km}}\right)^2 \left(\frac{M}{M_\odot}\right) \left(\frac{f_{orbit}}{400\,\text{Hz}}\right)^2 \left(\frac{10\text{Mpc}}{r}\right)$$

i.e. for km-scale receiver, $\delta L \sim 10^{-18}$ m $\sim 10^{-12}\ \lambda_{laser} \sim 10^{-8}$ Å $\sim 10^{-3}$ fm

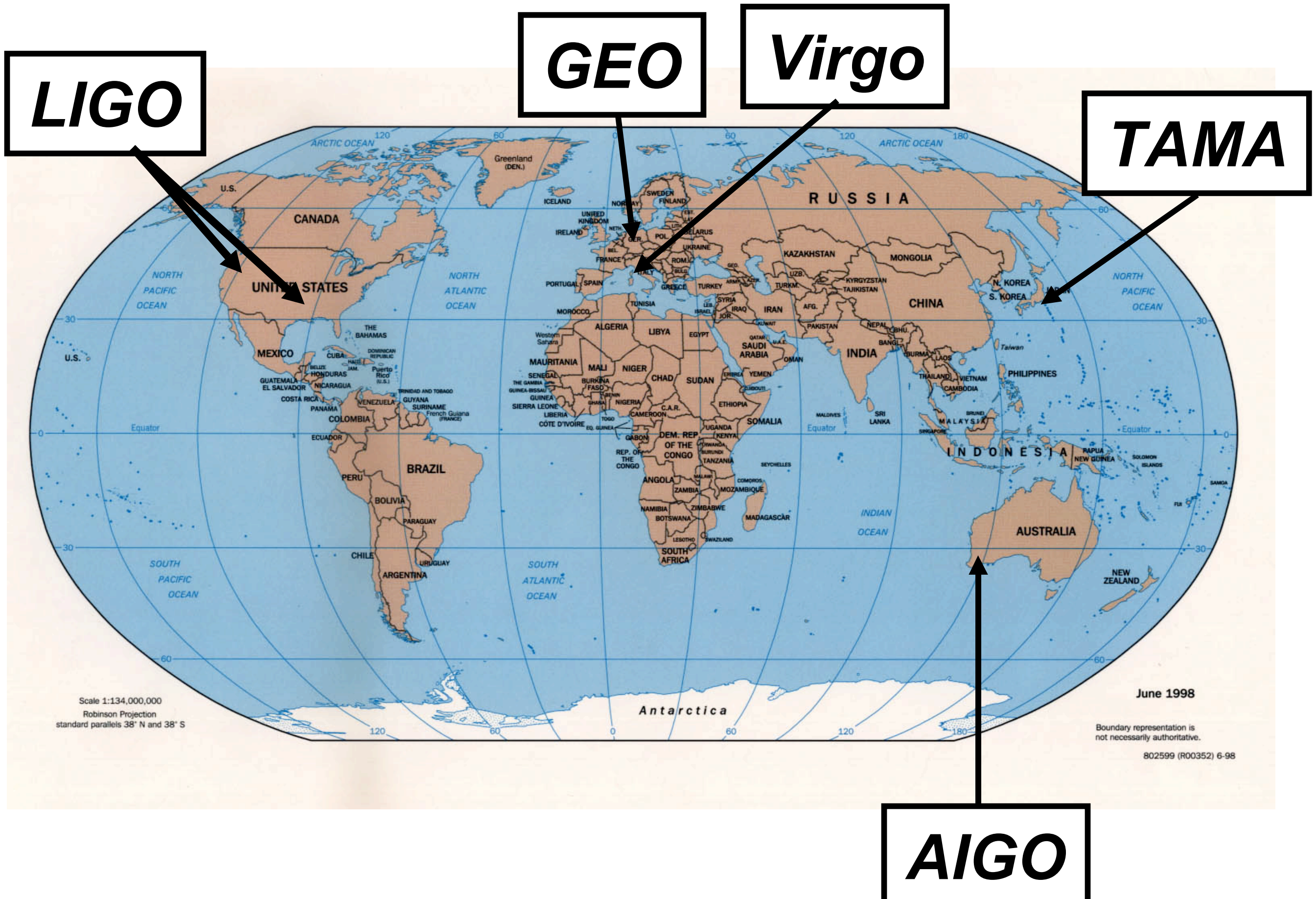
Interferometers: noise background

- Interferometry is limited by three fundamental noise sources
  - seismic noise at the lowest frequencies
  - thermal noise at intermediate frequencies
  - shot noise at high frequencies
- Additional 'technical' noise sources lurk below and must be controlled
- ELECTRONICS ARE CRITICAL



International Interferometer Network

Goal: simultaneous/coherent detections (within □~ $R_{\otimes}/c$ ~ 10ms)



Network offers:

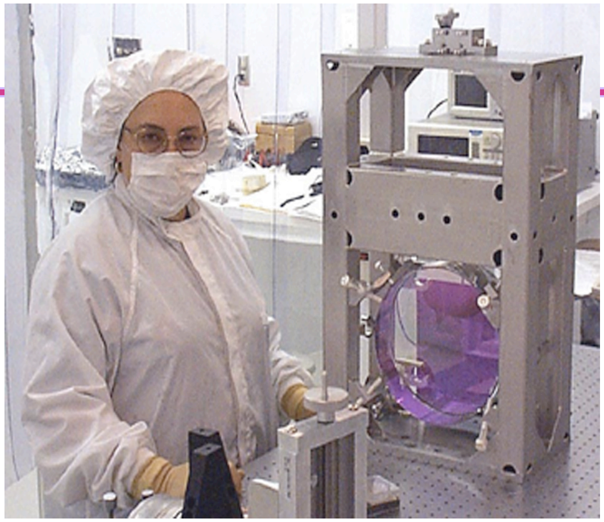
- Detection confidence
- Source sky location (link to □X-ray, optical, neutrino, radio objects)
- Source polarization

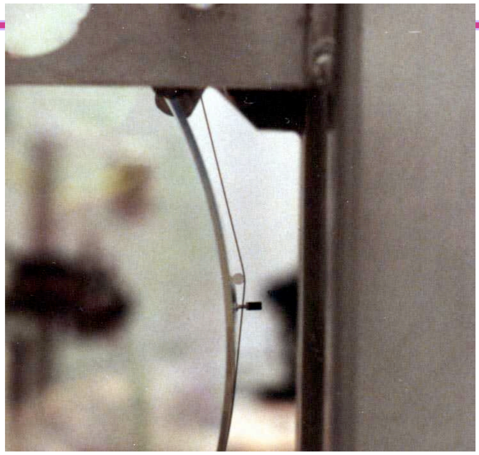
Beam Tubes

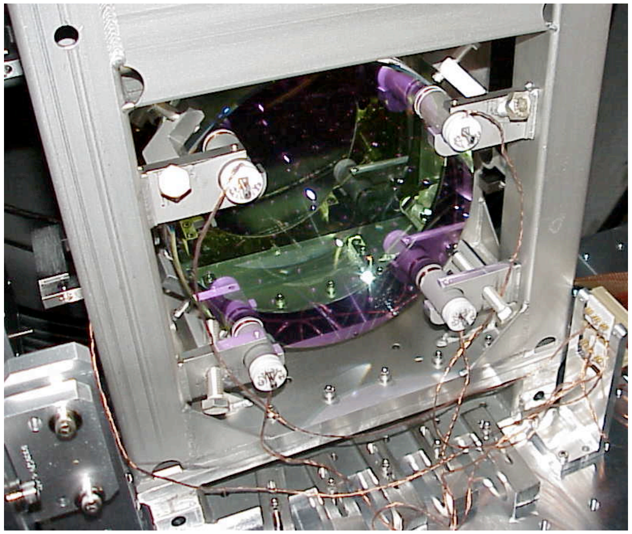
- Novel "low-hydrogen" 304L stainless steel (~10^6 lbs. of it)
- Spiral welded 1.2 m dia. pipes in 18 m sections
- Sections field-welded in mobile cleanrooms
- Vacuum baked by resistive heating
- 16 km with NO LEAKS
- 20,000 m^3 @ 10^{-8} torr; earth's largest high vacuum systems

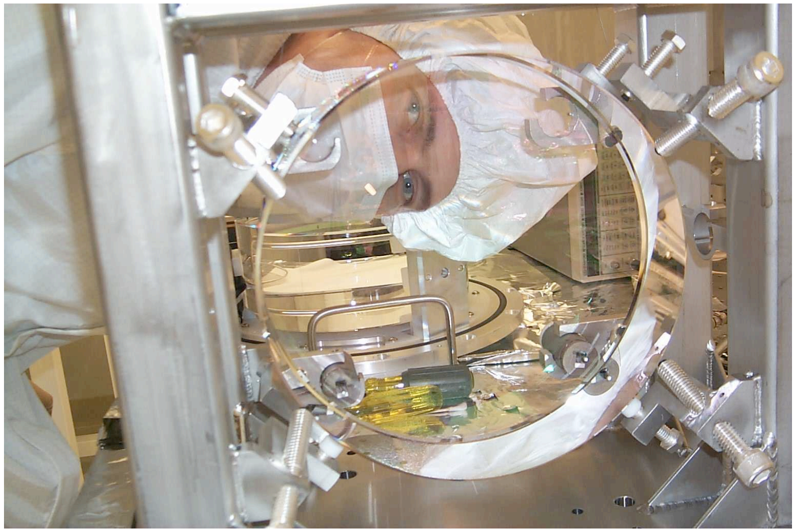
Vacuum Equipment

Core Optics Suspension and Control

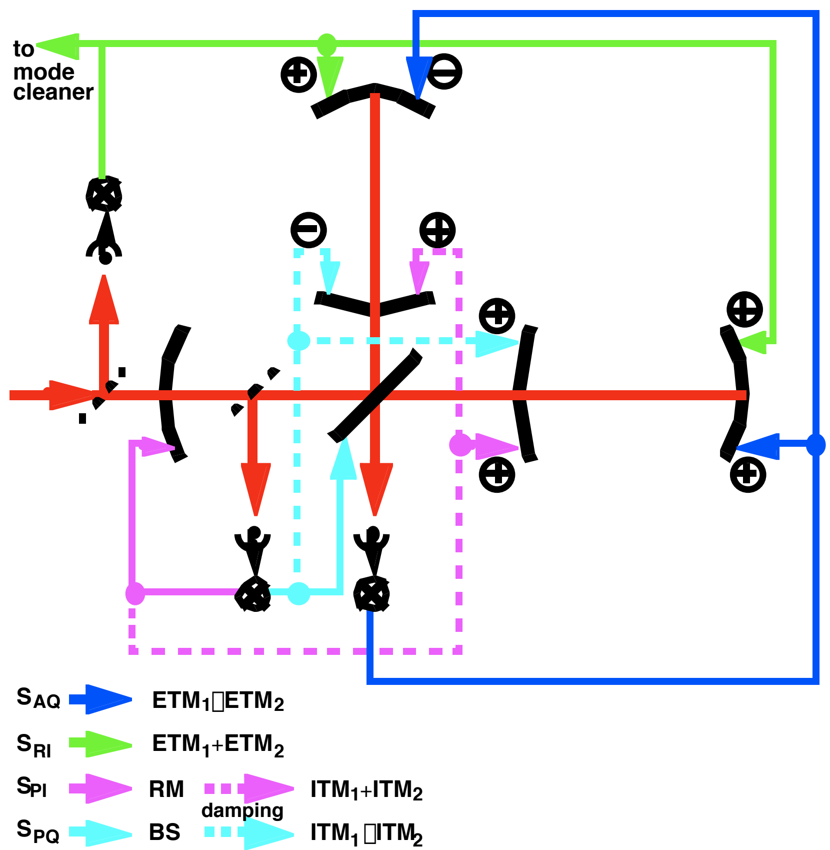




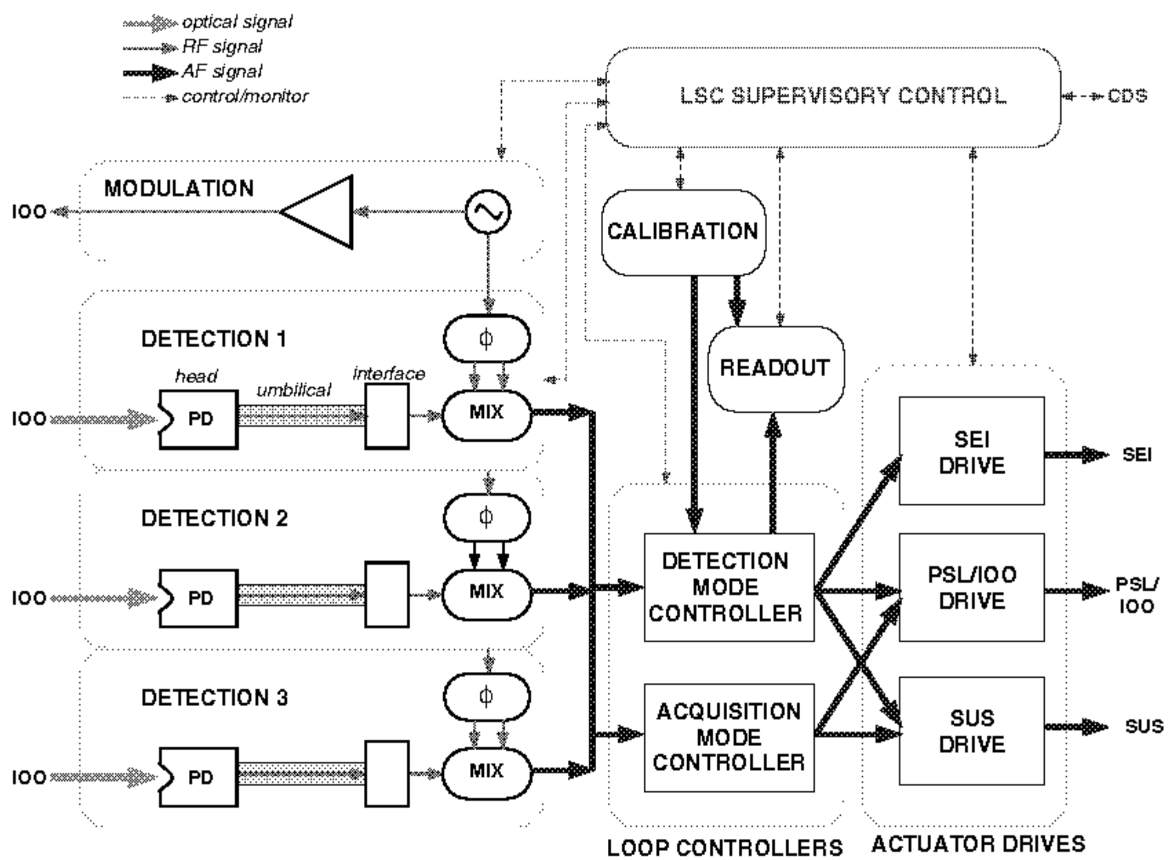




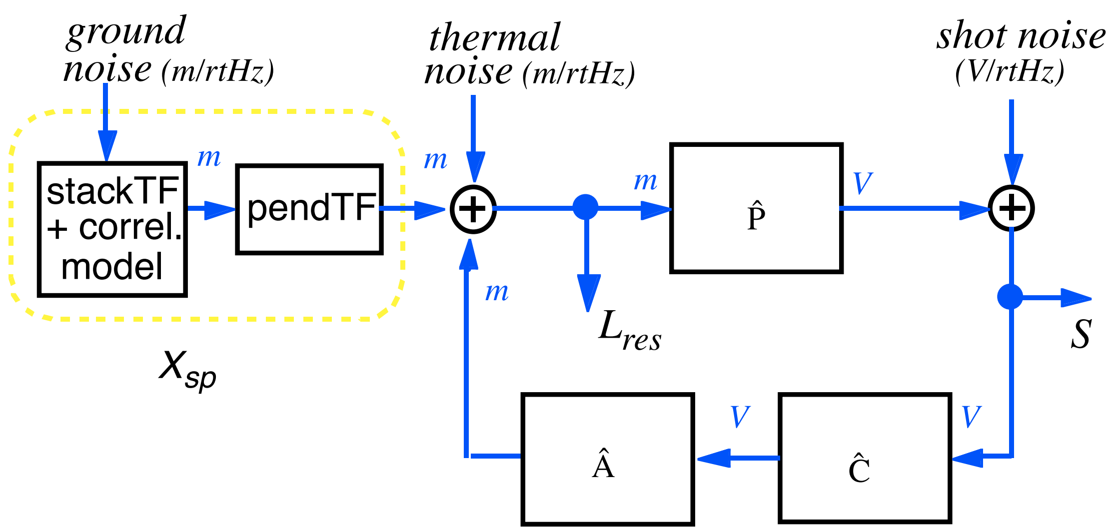
Control Actuation Paths



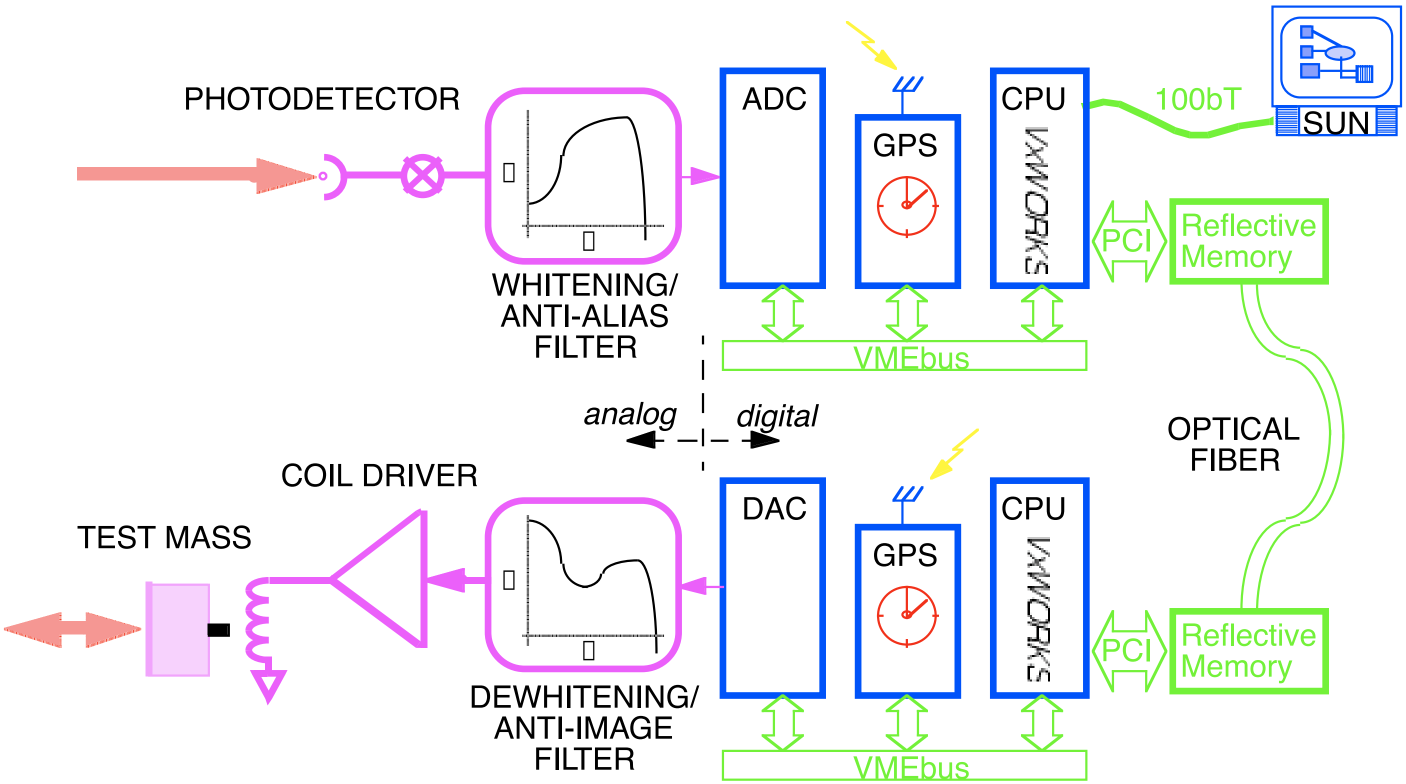
Functional Block Diagram (sensing & control)



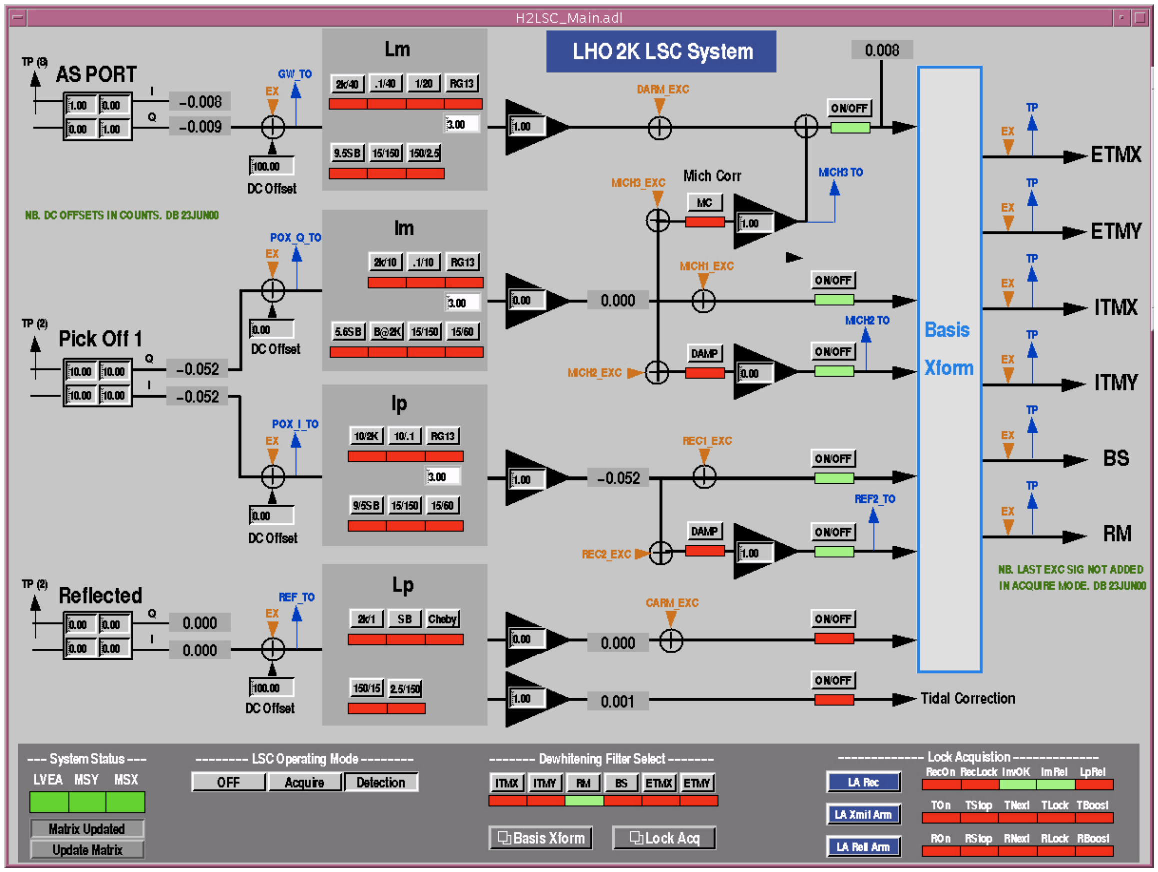
Example: control model for lengths (4 x 4)



Control Signal Processing Architecture



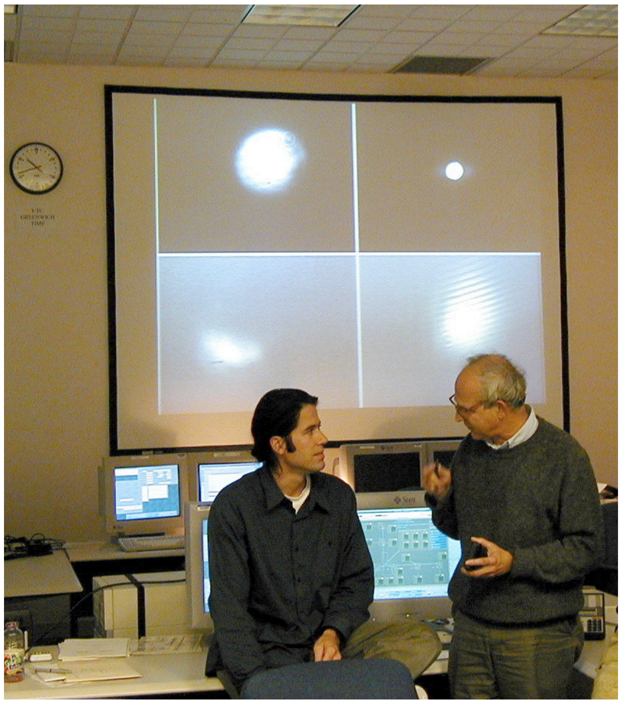
EPICS Control Screen (example: LSC)



Electronic equipment subsystems

- Interferometer Sensing & (realtime) Controls
  - PreStabilized Laser and Input Optics controls)
  - Analog (PreStabilized Laser and Input Optics) & mixed signal (main)
  - Incl. RF mod/demod, conversion filtering, control loop filtering, digital signal processing
  - ~ hundred channels/ifo (with test points), 2 and 16 ksamples/sec
- SUSpensions & SEIsmic isolation
  - Analog initially, moving to digital/mixed signal implementation
- EPICS (supervisory) control
- Global Diagnostics System; TP excitation & monitoring tools
- Physical Environment Monitors; auxiliary sensors
- Data AcQuisition; kChannels, up to 16 MB/s per IFO
- Vacuum Equipment & FACilities

Initial LIGO Status



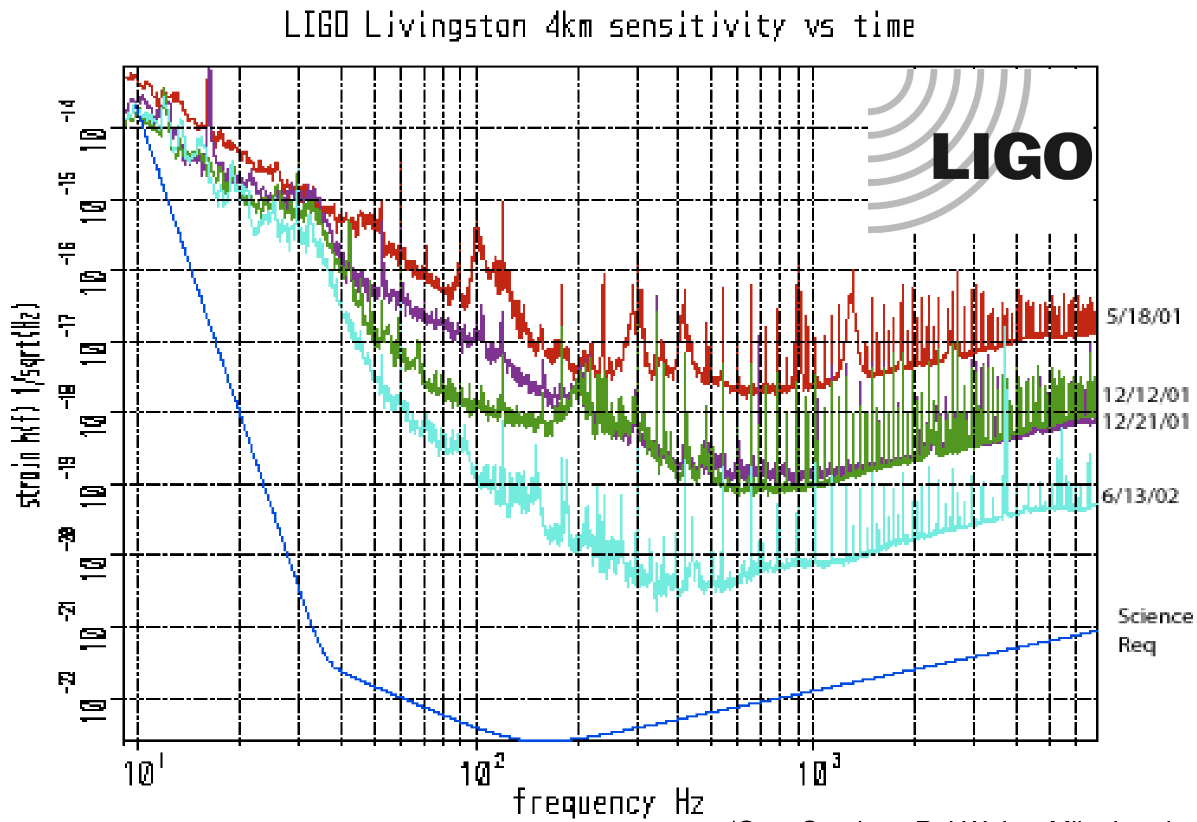
Rai Weiss (MIT) and
Rob Schofield (Oregon) at
W2k "First Lock", 10/20/00

- All 3 interferometers complete and operating
- Data analysis hw/sw systems in place
- 7 brief "engineering" data runs completed
  - Including LA-WA coincidence, data analysis practice
- "S1" initial science observing run set for 8/23
- Commissioning, SNR improvement, problem fixes underway, interleaved with data runs
- Significant strides in SNR since "first lock"

BUT

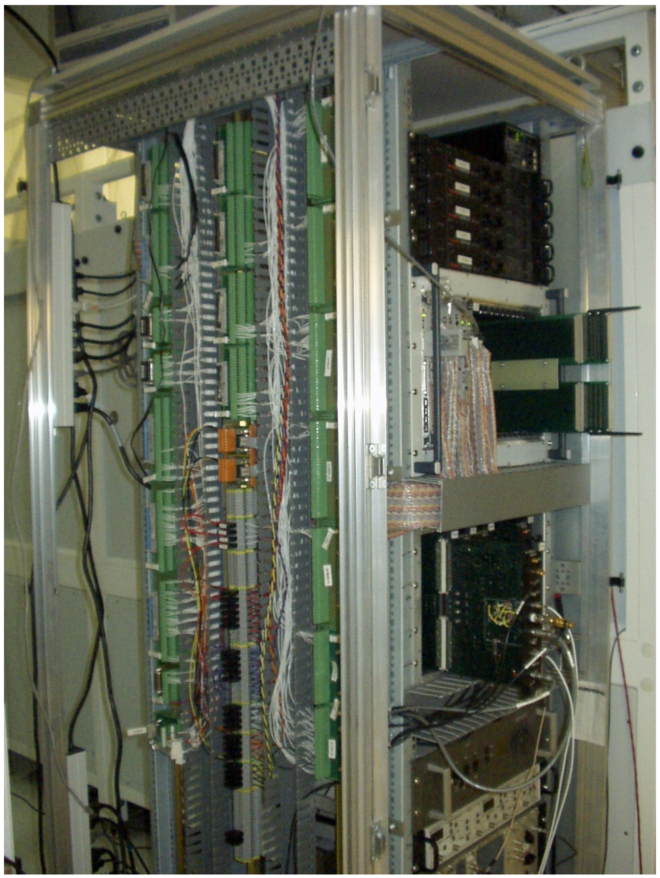
- Still ~100x design noise @ kHz, worse @ 100 Hz
- Most struggles involve balancing electronics dynamic range, loop gain, and NOISE

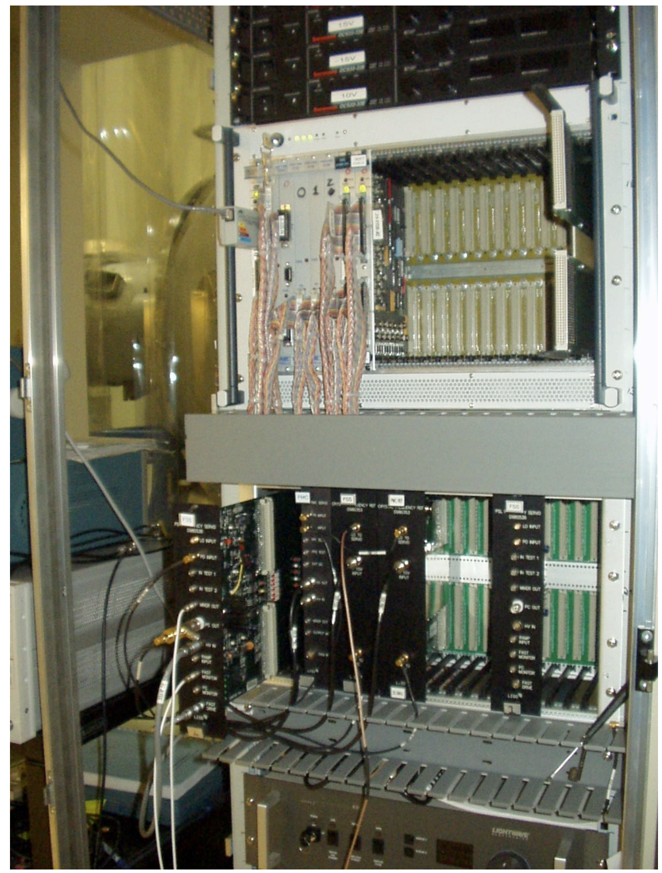
Sensitivity progress, LLO 4km



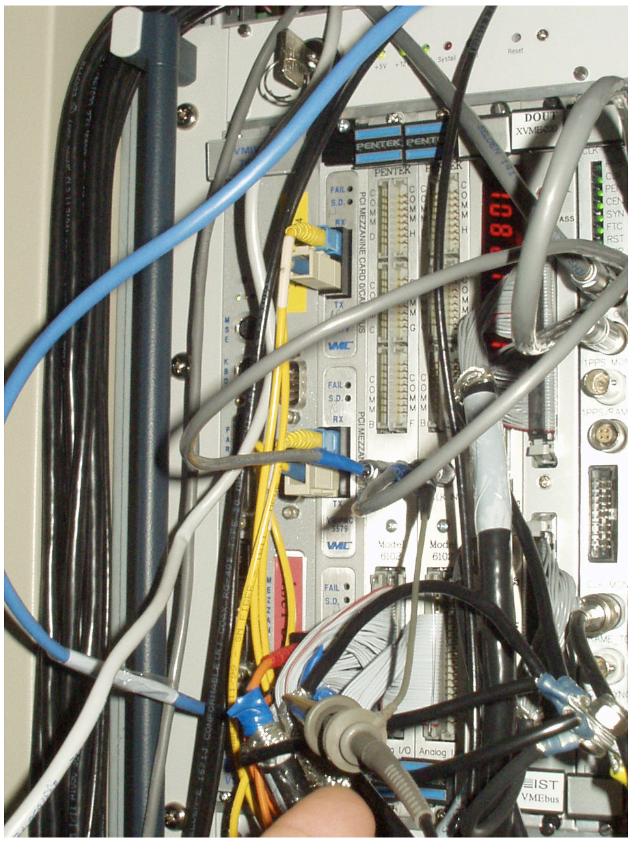
(Gary Sanders, Rai Weiss, Mike Landry, Rana Adhikari)

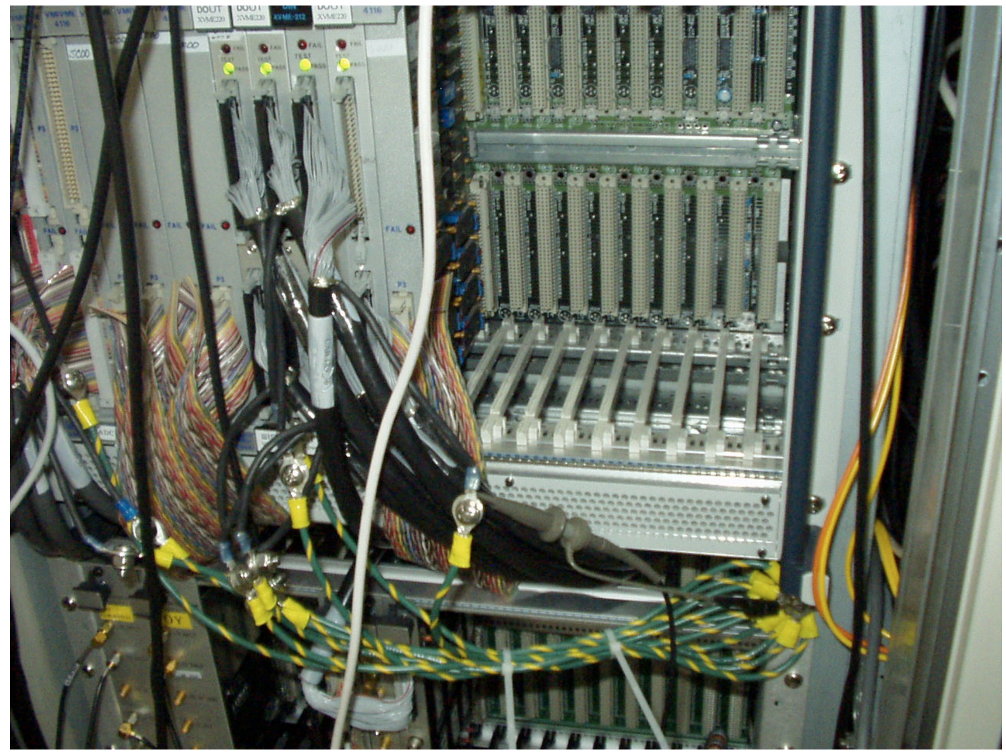
'What we thought it should look like:' RF/analog laser controls w/ EPICS VME crate



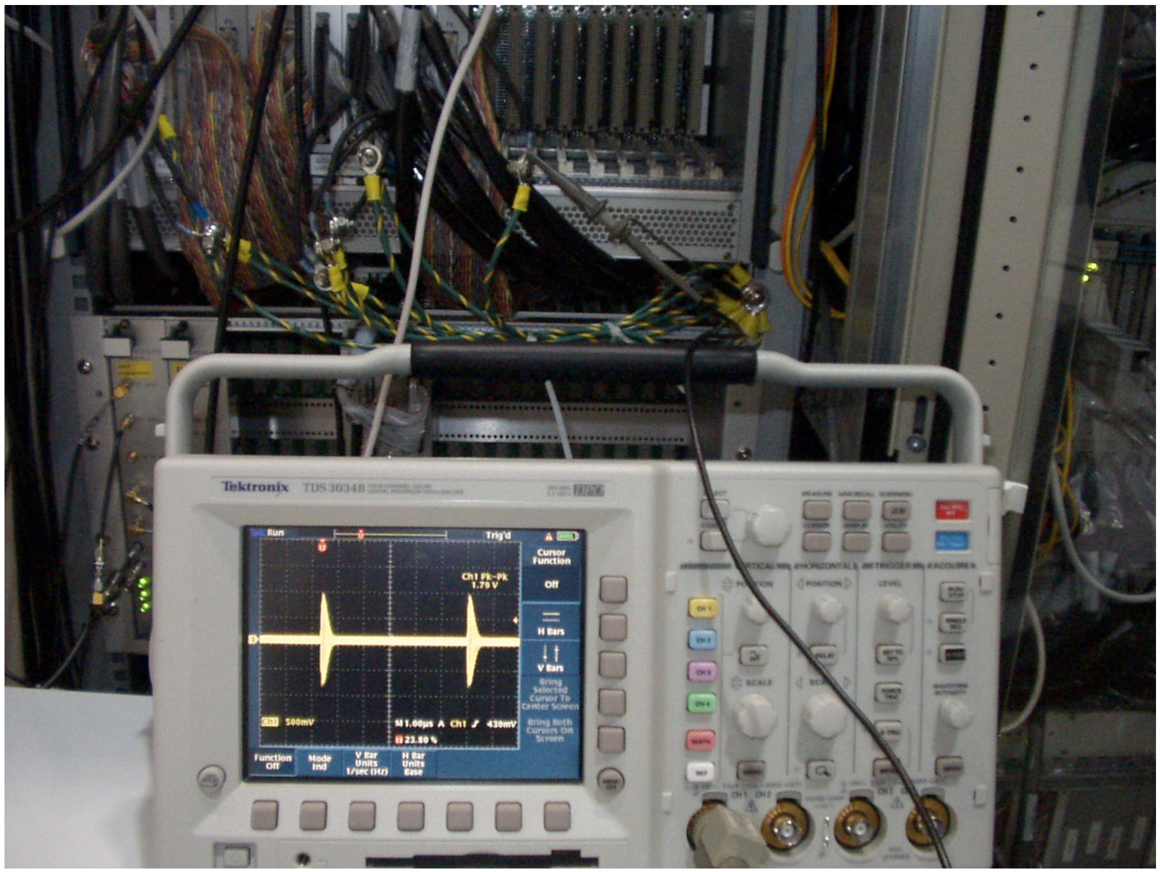


How it turned out: LSC & EPICS VME crates

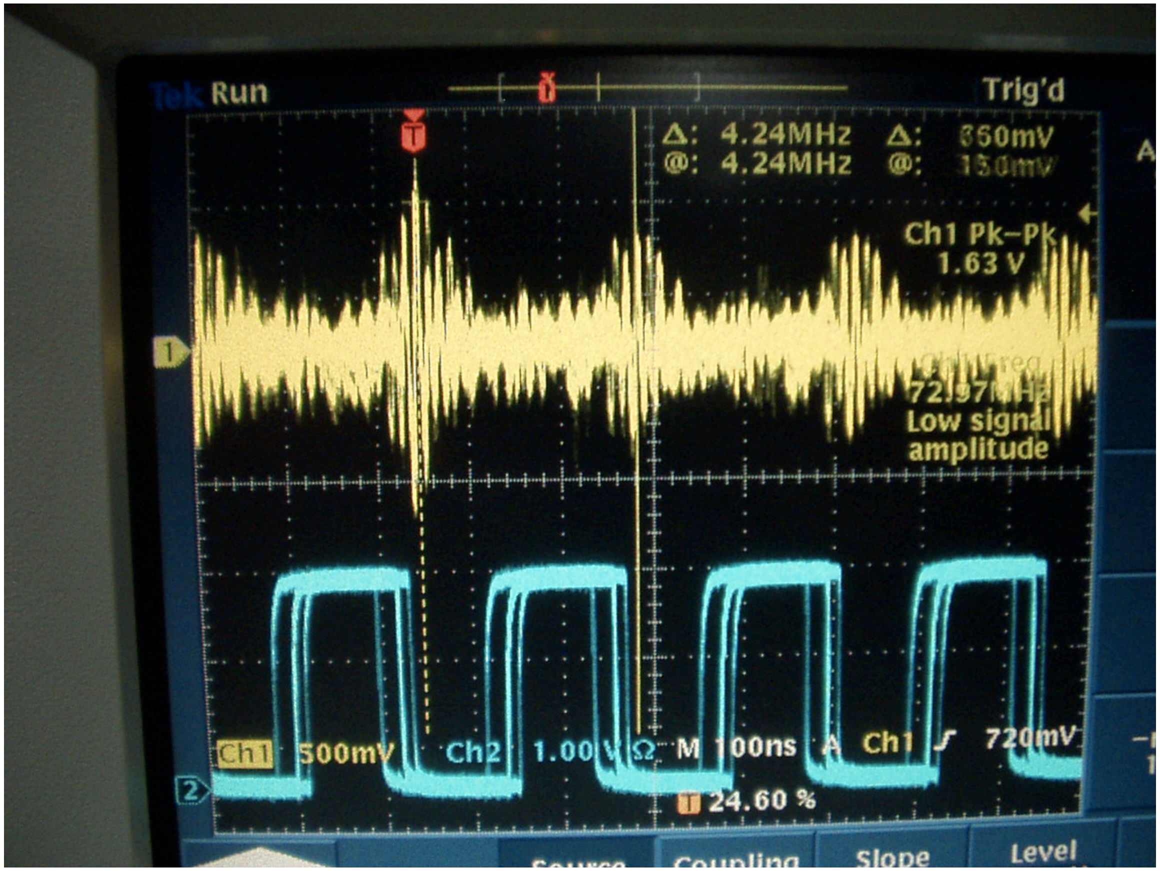




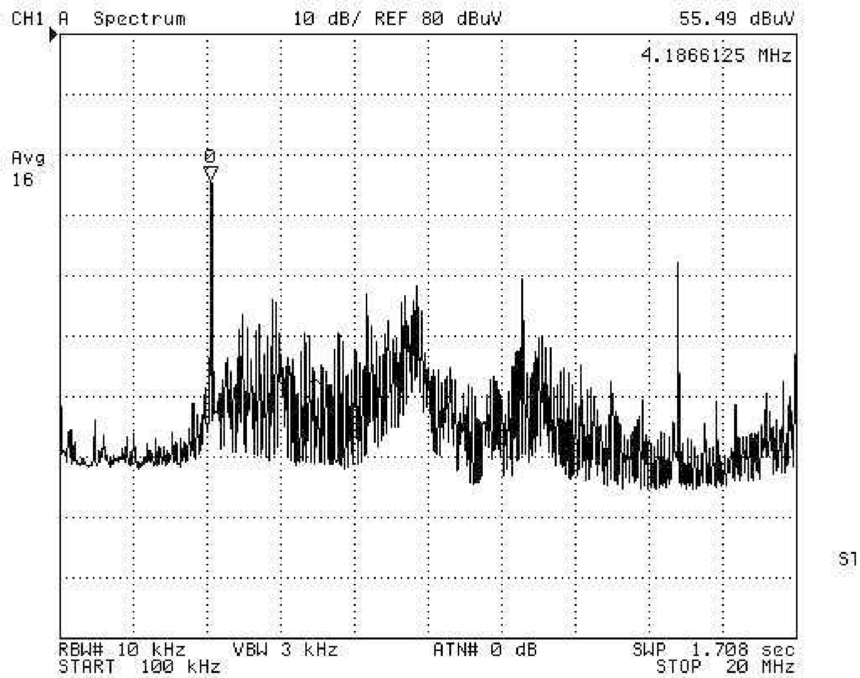
Volt-level spikes on signal shields

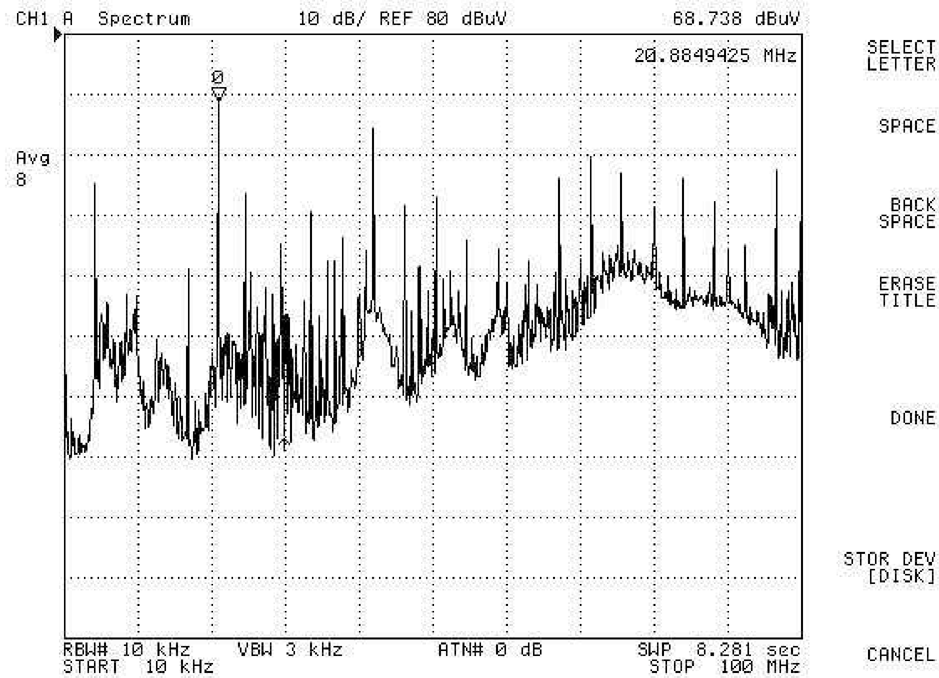


ADC input signal hash (top), main clock (bottom)



18 cm dipole 1m from VME crate (20 MHz)





Current issues for LIGO redesign effort

- DC power supply radiation & conduction
  - remote supplies, swap linears for switchers?
- 60 Hz ground loops & magnetic shielding (affects other goals)
  - star grounding? isolation transformers?
- ADC & DAC protection (from themselves?)
- VME crate clock/bus hash containment
  - seal up the crates? double shielding? modify commercial boards?
- Analog crate defenses, including backplane, cabling, connectors
  - custom crates? abandon Eurocard format? opto-isolate control lines?
- Low-level rack-to-rack analog transmission
  - differential driver/receivers with floating power?
- Practical issues:
  - need to phase upgrades and maintain working instruments in between
  - need to salvage as many current boards as possible ($, manpower, time)