LIGO Status and Plans

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March 13, 2000

LIGO-G000170-00-M

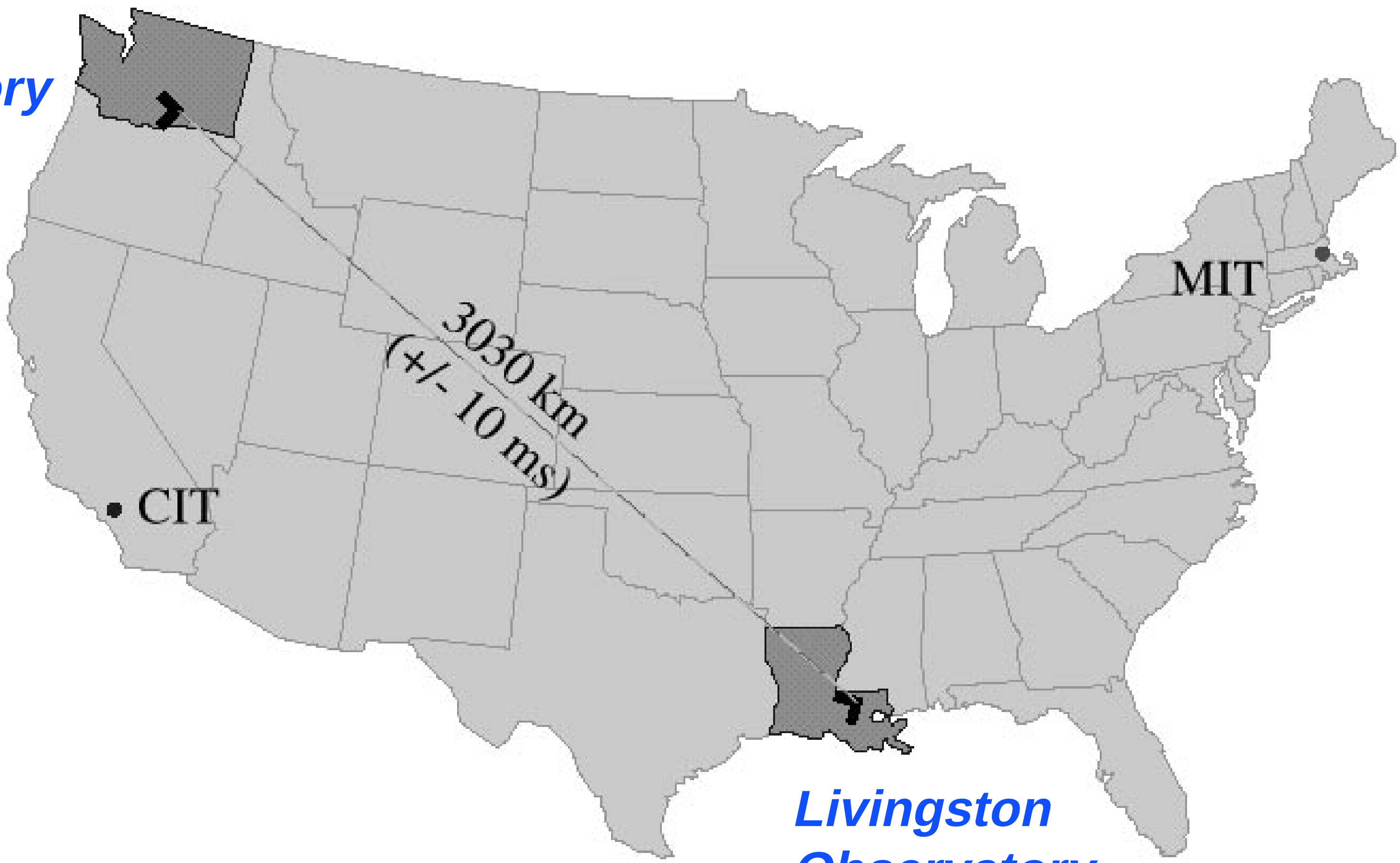
LIGO Plans

schedule

1996	Construction Underway (mostly civil)
1997	Facility Construction (vacuum system)
1998	Interferometer Construction (complete facilities)
1999	Construction Complete (interferometers in vacuum)
2000	Detector Installation (commissioning subsystems)
2001	Commission Interferometers (first coincidences)
2002	Sensitivity studies (initiate LIGOI Science Run)
2003+	LIGO I data run (one year integrated data at $h \sim 10^{-21}$)
2005	Begin LIGO II installation

LIGO Sites

Hanford Observatory



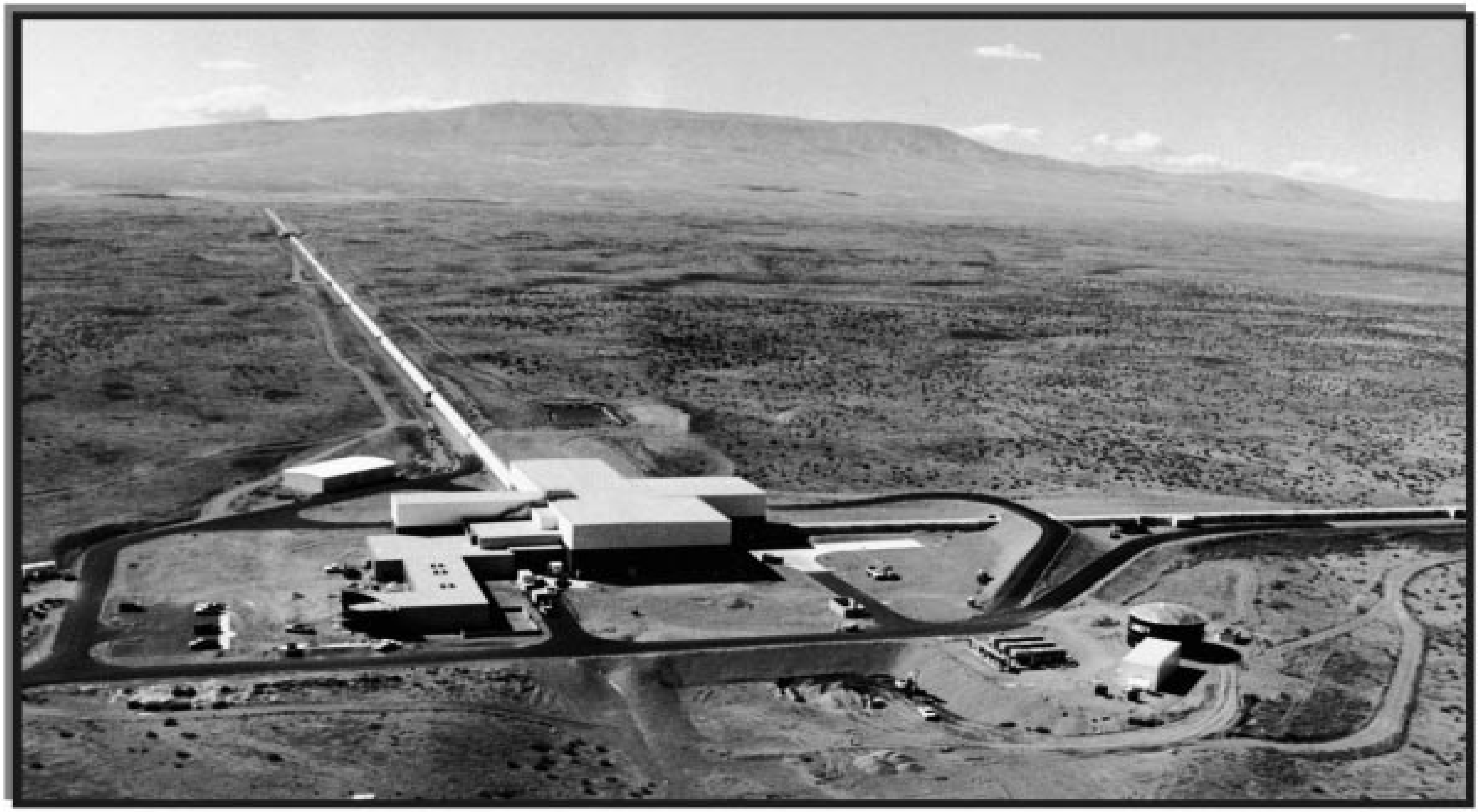
Livingston Observatory

LIGO

Livingston Observatory

LIGO

Hanford Observatory



LIGO Facilities

Beam Tube Enclosure

- **minimal enclosure**
- **reinforced concrete**
- **no services**

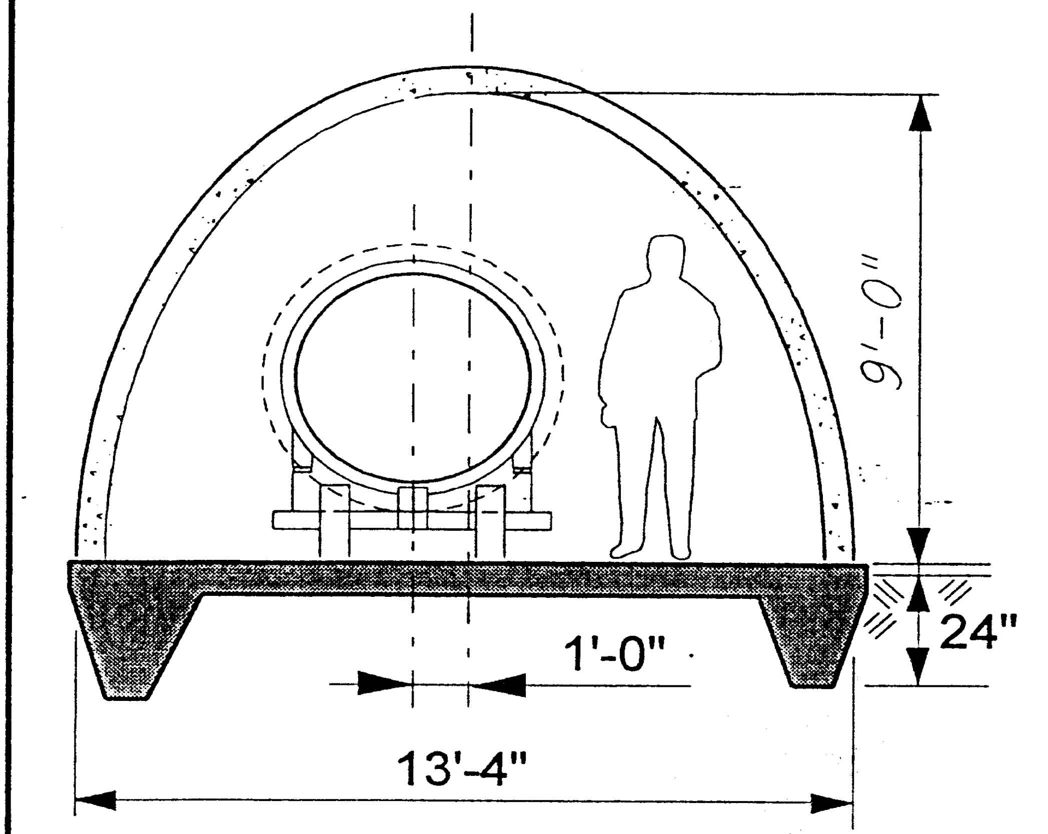


Figure 2.1-1 -- Cross Section of Design Baseline at Hanford

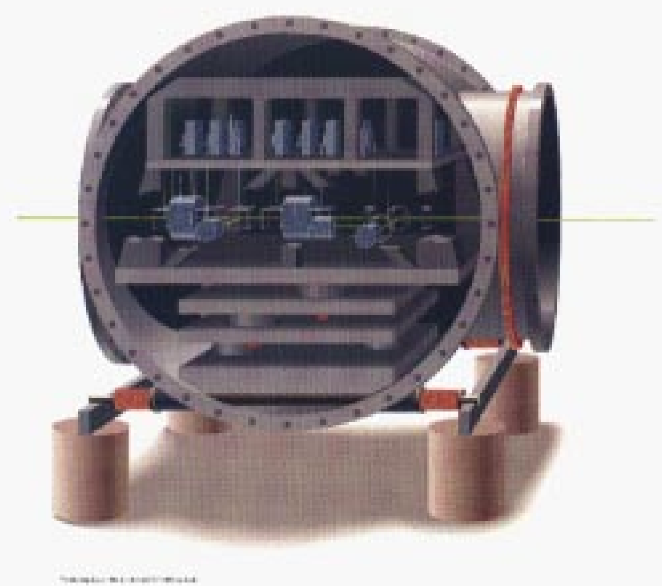
LIGO
Beam Tube

- LIGO beam tube under construction in January 1998
- 65 ft spiral welded sections
- girth welded in portable clean room in the field

LIGO

vacuum equipment

Vacuum Chambers



HAM Chambers

BSC Chambers

Seismic Isolation

Constrained layer damped Springs

Seismic Isolation Systems

Progress

» production and delivery of components almost complete

» early quality problems have mostly disappeared

» the coarse actuation system for the BSC seismic isolation systems has been installed and tested successfully in the LVEA at both Observatories

» Hanford 2km & Livingston seismic isolation system installation has been completed, with the exception of the tidal compensation (fine actuation) system

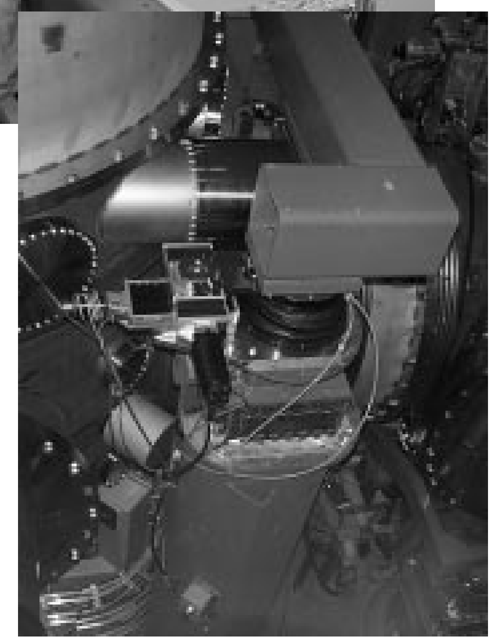
» Hanford 4km seismic isolation installation is ~75% complete

HAM Door Removal (Hanford 4km)

Seismic Isolation Systems

Support Tube Installation

Stack Installation



Coarse Actuation System

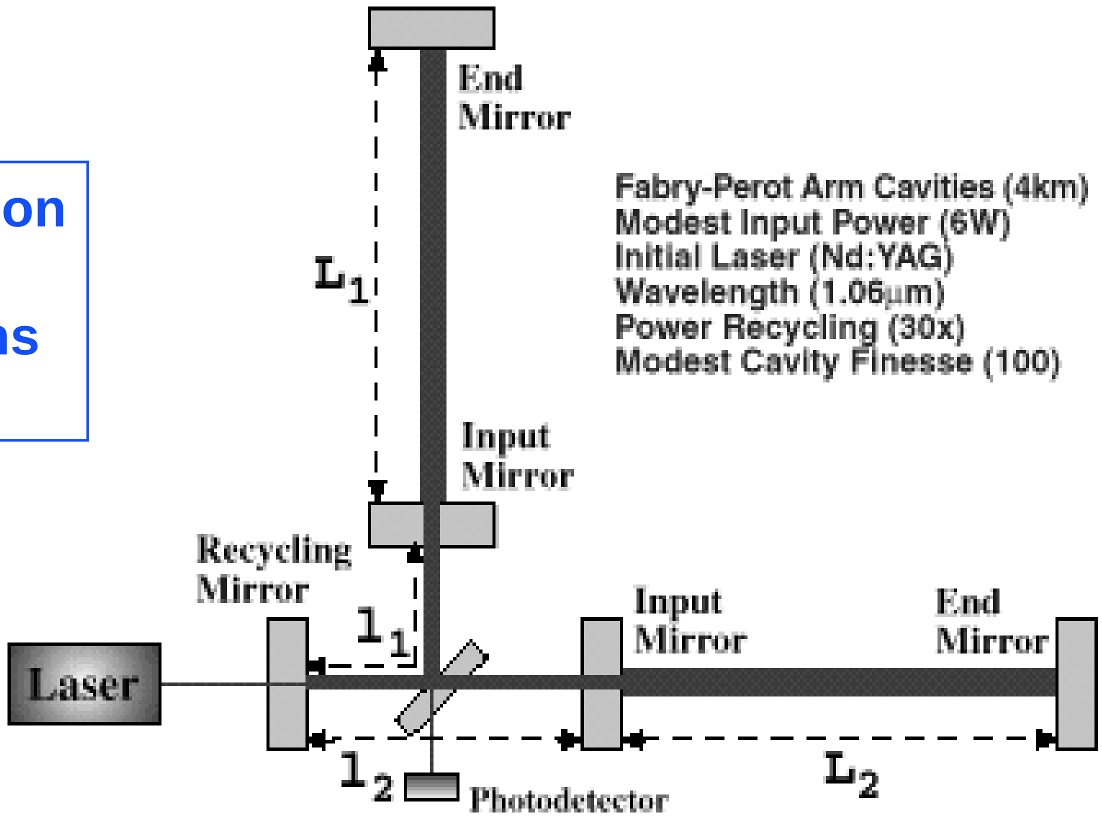
LIGO I

interferometer

- **LIGO I configuration**

- **Science run begins in 2002**

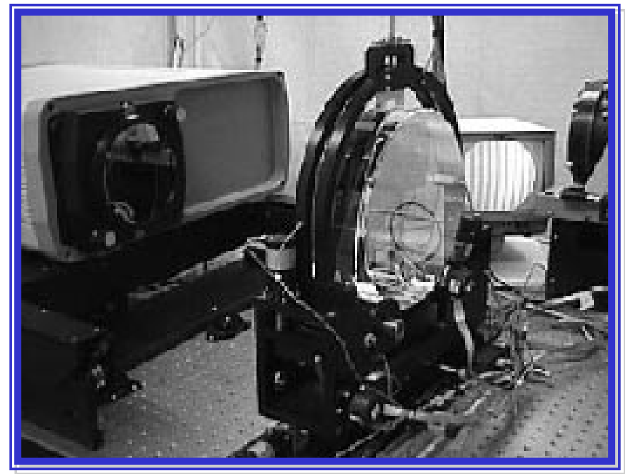
Initial LIGO Interferometer Configuration



Optics

mirrors, coating and polishing

- All optics polished & coated
  - » Microroughness within spec. (<10 ppm scatter)
  - » Radius of curvature within spec. ($\delta R/R < 5\%$)
  - » Coating defects within spec. (pt. defects < 2 ppm, 10 optics tested)
  - » Coating absorption within spec. (<1 ppm, 40 optics tested)



Input Optics

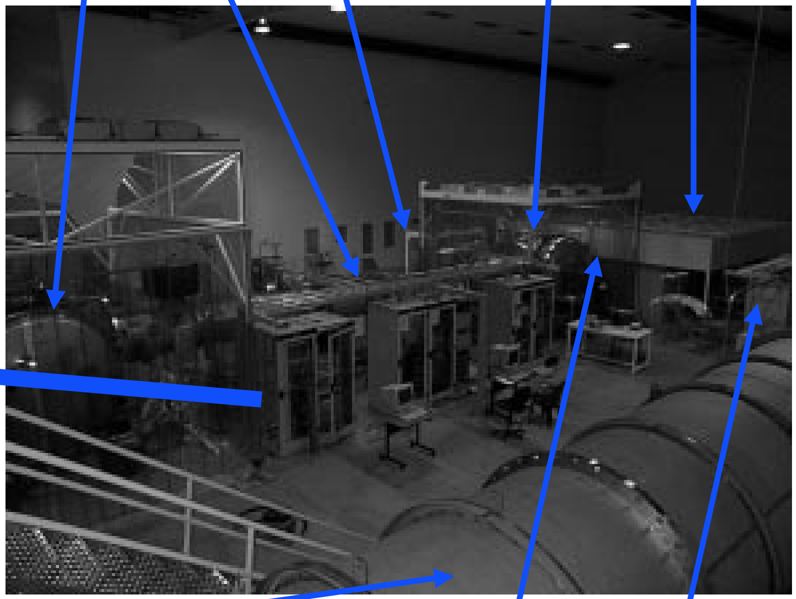
installation & commissioning

- **The 2km Input Optics subsystem installation has been completed**
  - » **The Mode Cleaner routinely holds length servo-control lock for days**
  - » **Mode cleaner parameters are close to design specs, including the length, cavity linewidth and visibility**
  - » **Further characterization is underway**

Input Optics

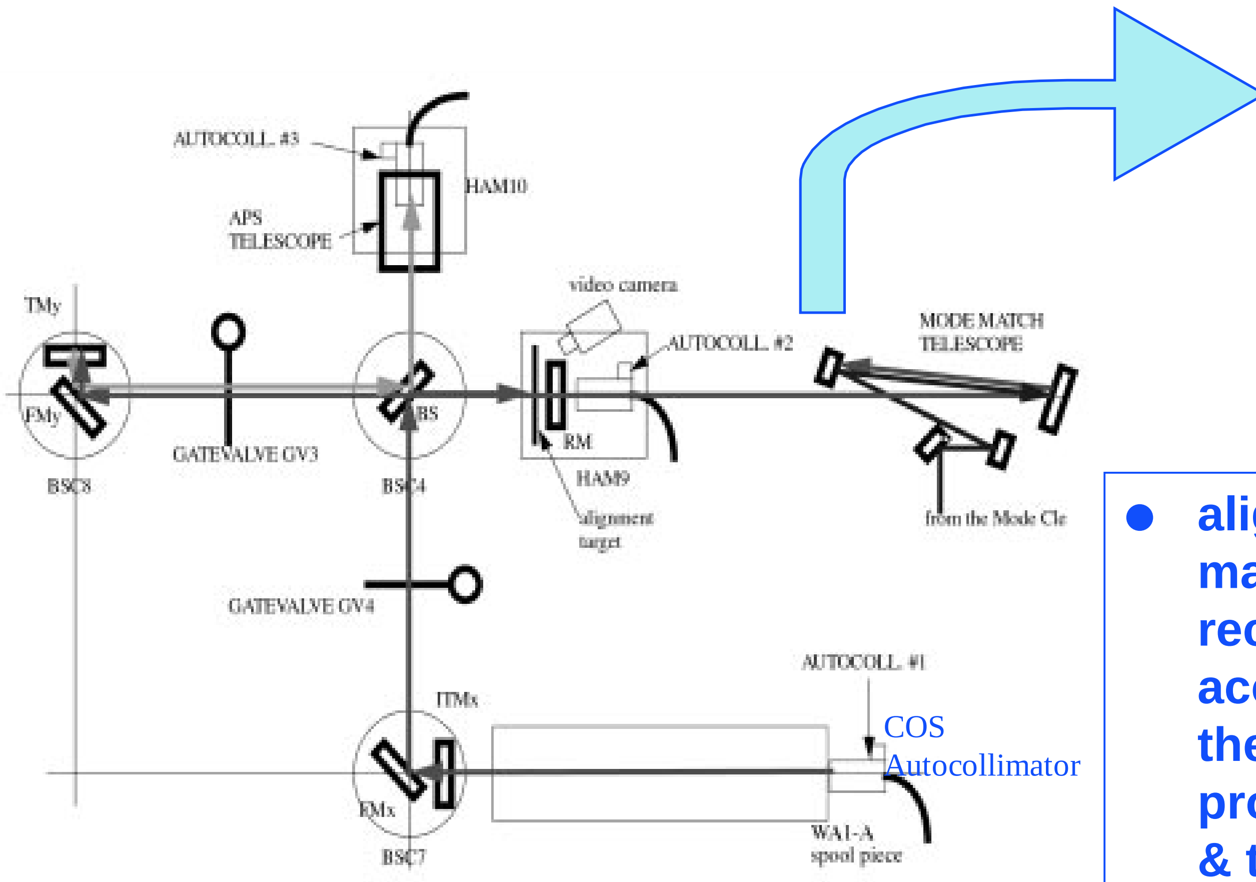
Hanford 2 km

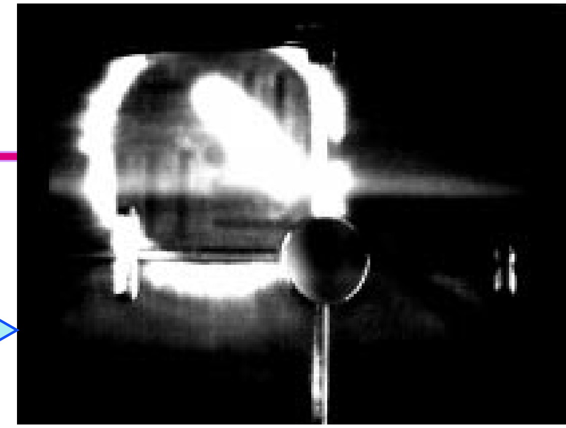
Control System Racks



Input Optics Section

Recycling Cavity Alignment





Projected reticule pattern & PSL beam on target in front of MMT2

- alignment of the mode match telescope to the recycling cavity was accomplished by aligning the PSL beam to the projected reticule pattern & then by retroreflection from the recycling mirror

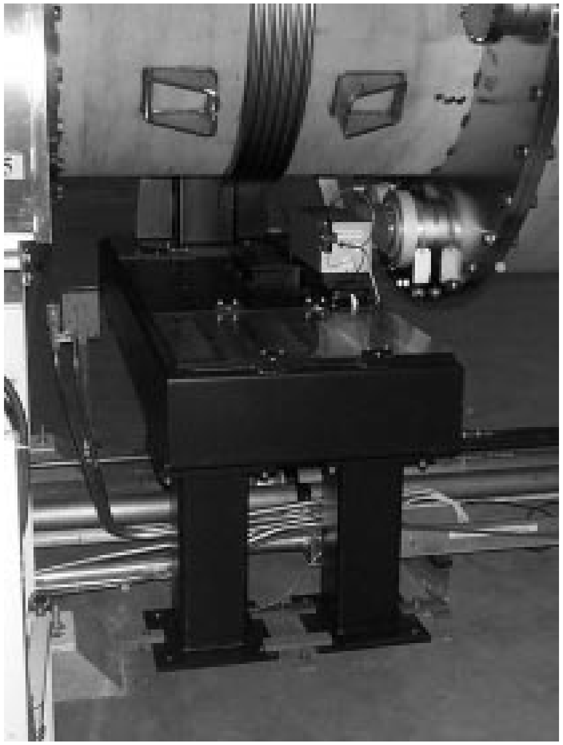
Recycling Cavity Alignment

Adjusting the Fold Mirror Alignment

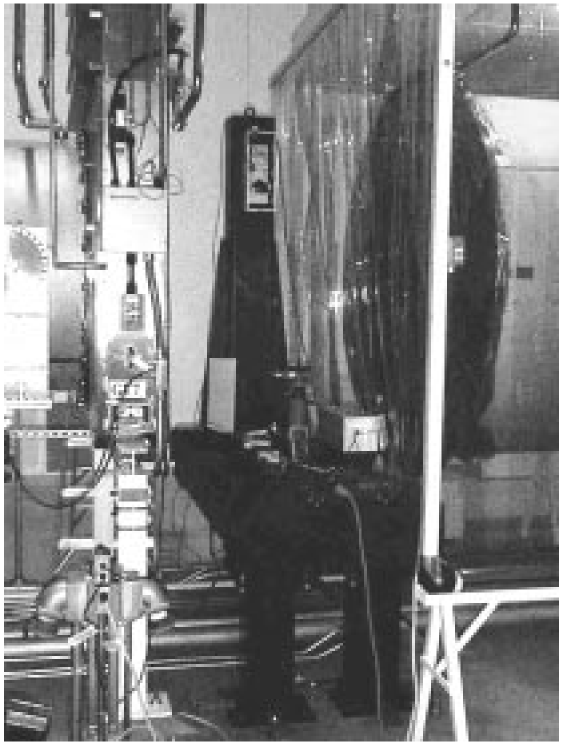
Initial Alignment System

Optical Levers

- **Optical levers have been installed, aligned & are operational for all core optics in the 2km interferometer**



Input Test Mass Optical Lever



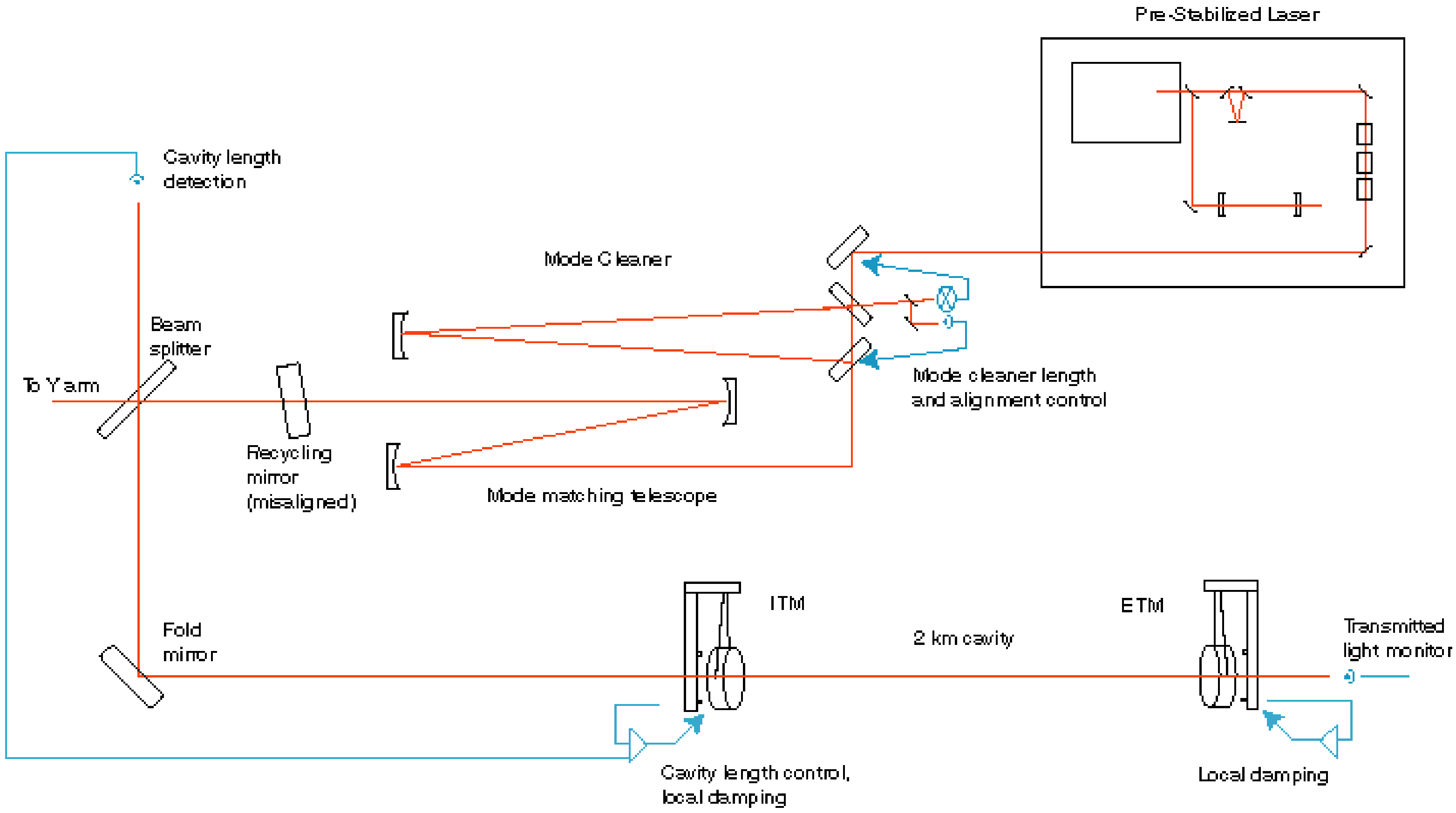
Transmit & Receive modules visible with spool piece removed for input test mass alignment

Commissioning Configurations

- Mode cleaner and Pre-Stabilized Laser
- Michelson interferometer
- 2km one-arm cavity

- At present, activity focussed on Hanford Observatory
- Mode cleaner locking imminent at Livingston

Schematic of system



Commissioning

Pre-Stabilized Laser-Mode Cleaner

- **Suspension characterization**
  - » **actuation / diagonalization**
  - » **sensitivity of local controls to stray Nd:YAG light**
  - » **Qs of elements measured, 3 10^{-5} - 1 10^{-6}**

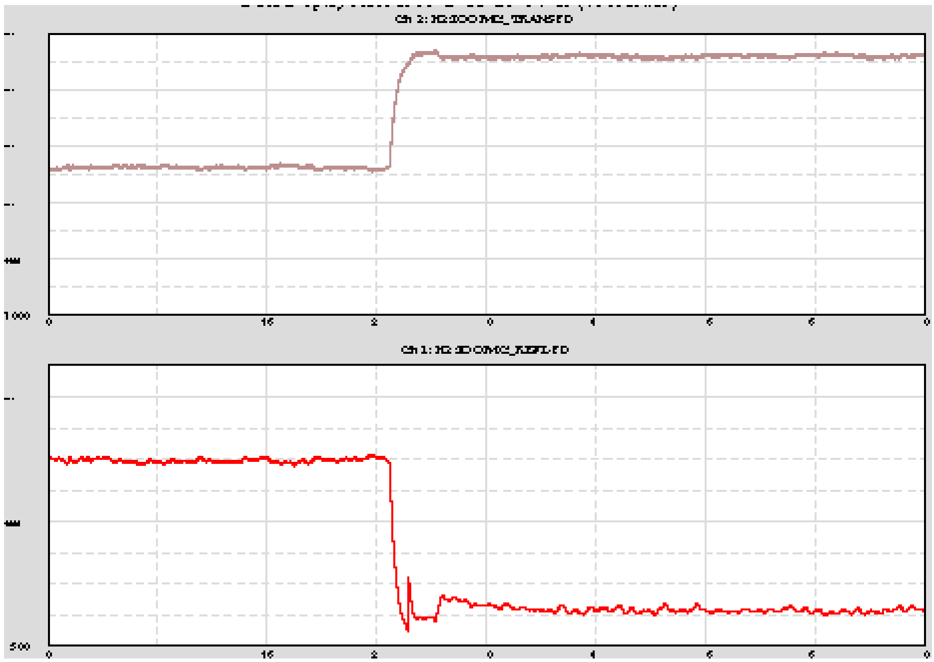
- **Laser - Mode Cleaner control system shakedown**

- **Laser frequency noise measurement**

Wavefront sensing

Mode Cleaner cavity

- **Alignment system function verified**



Michelson Interferometer

- **Interference quality of recombined beams (>0.99)**
- **Measurements of Qs of Test Masses**

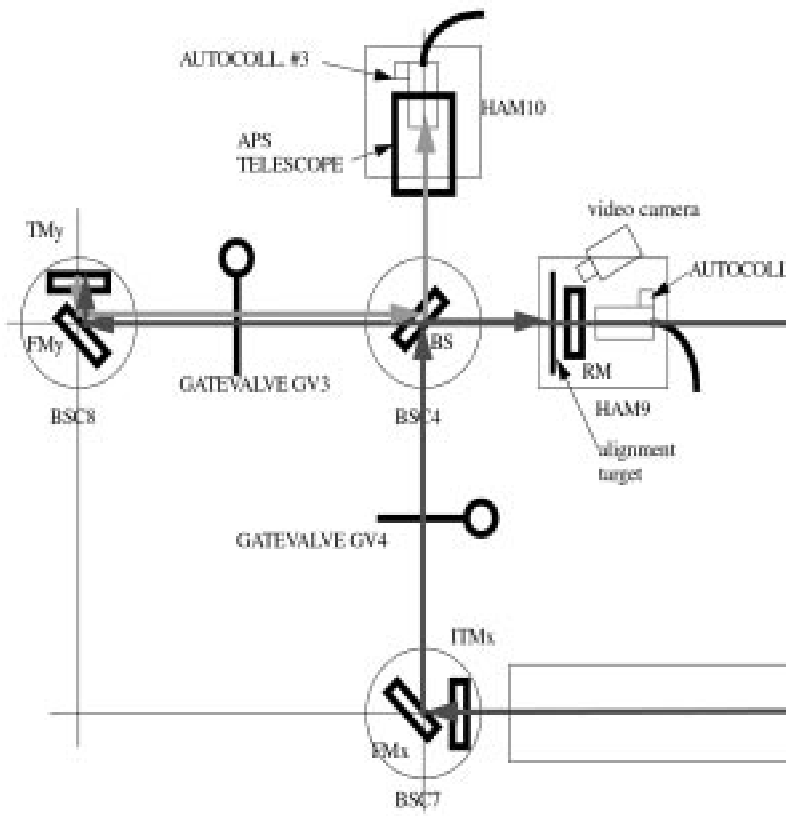


Table 1. Internal Resonance Measurement Data

Optic Name	*Resonant Frequency fo (kHZ)*	*Mode Name*	*Q Measured*	*Q Theoretical*
ITMx	6.7475	Butterfly	1.40×10^6	1.3×10^6
ITMx	9.395	Drum Head	*6.16×10^5	
ITMx	14.3737	Breathing	1.20×10^7	
BS	3.7337	Butterfly	1.85×10^6	
BS	5.4775	Drum Head	2.50×10^4	
BS	7.812	3-Fold Radial	2.65×10^5	2.6×10^6
BS	11.1387		3.60×10^5	
ITMy	9.3975	Drum Head	9.98×10^5	1.3×10^6

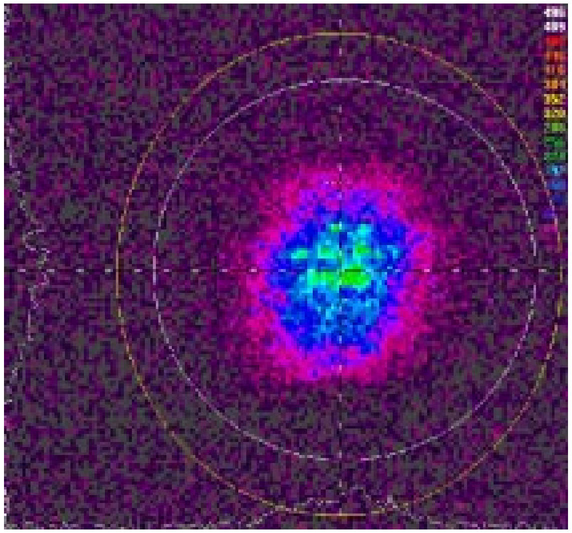
*A rough estimate compared to other values in table (data analysis method for this value was different). Betsy Weaver 1/19/00

2km Fabry-Perot cavity

- Includes all interferometer subsystems
  - » many in definitive form; analog servo on cavity length for test configuration
- confirmation of initial alignment
  - » ~100 microrad errors; beams easily found in both arms
- ability to lock cavity improves with understanding 0 sec 12/1 flashes of light
  - » 0.2 sec 12/9
  - » 2 min 1/14
  - » 60 sec 1/19
  - » 5 min 1/21 (and on a different arm)
  - » 18 min 2/12
  - » 1.5 hrs 3/4 (temperature stabalize pre modecleaner)

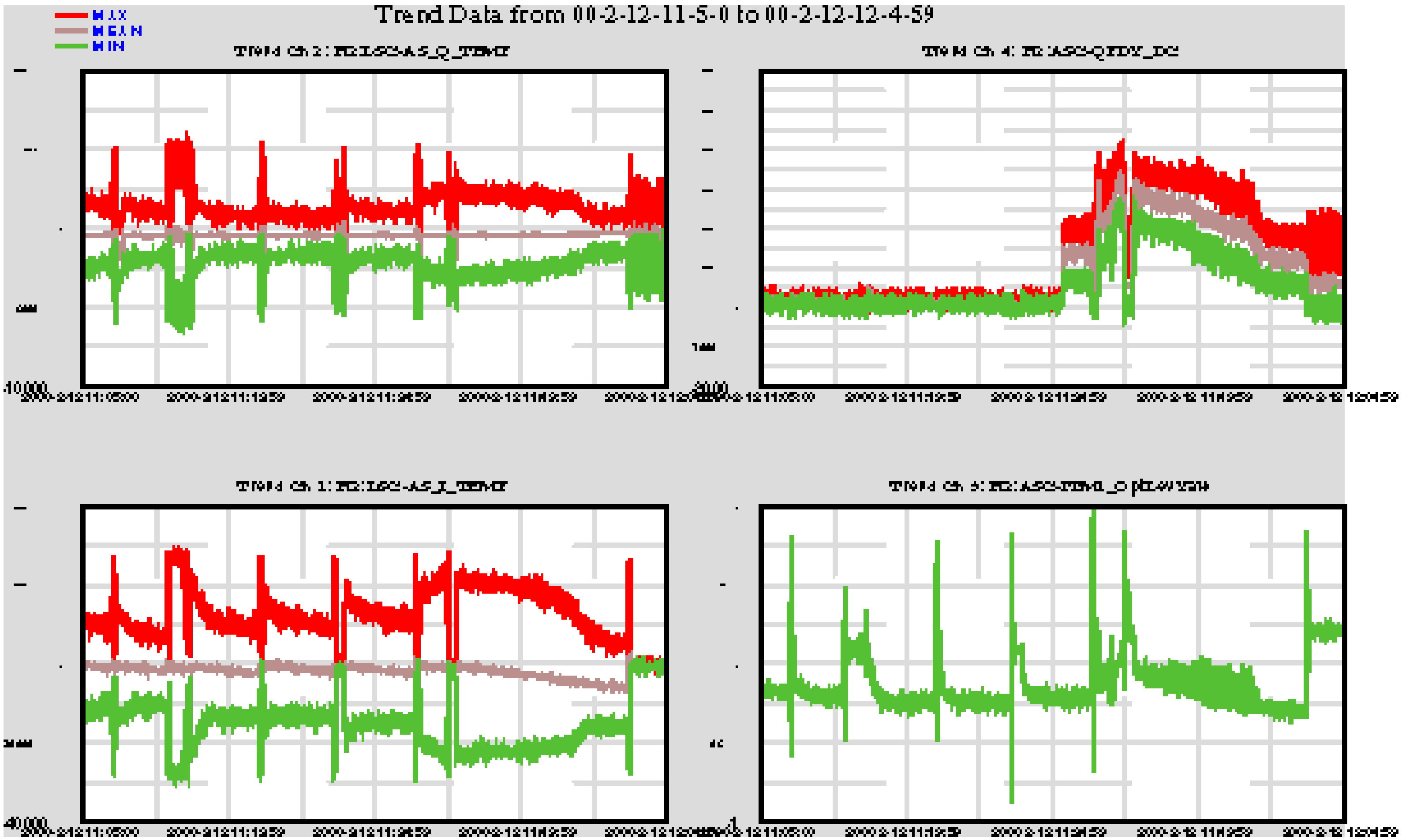
2km Fabry-Perot cavity

- models of environment
  - » temperature changes on laser frequency
  - » tidal forces changing baselines
  - » seismometer/tilt correlations with microseismic peak
- mirror characterization
  - » losses: ~6% dip,
    excess probably due to poor centering
  - » scatter: appears to be
    better than requirements
  - » figure 12/03 beam profile



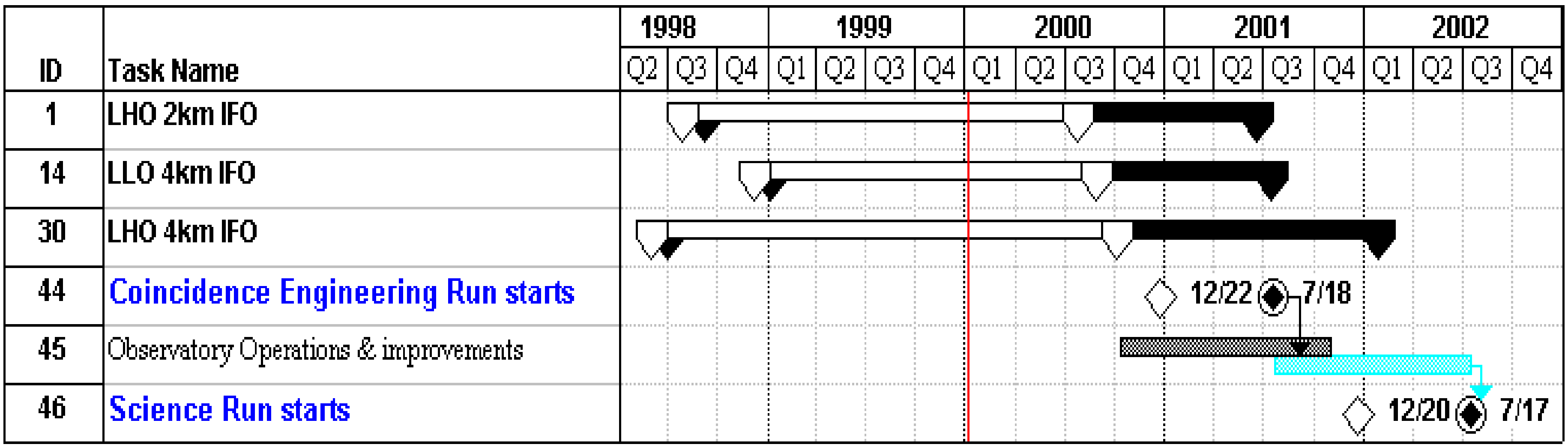
2km Fabry-Perot cavity

15 minute locked stretch



Schedule

commissioning and testing

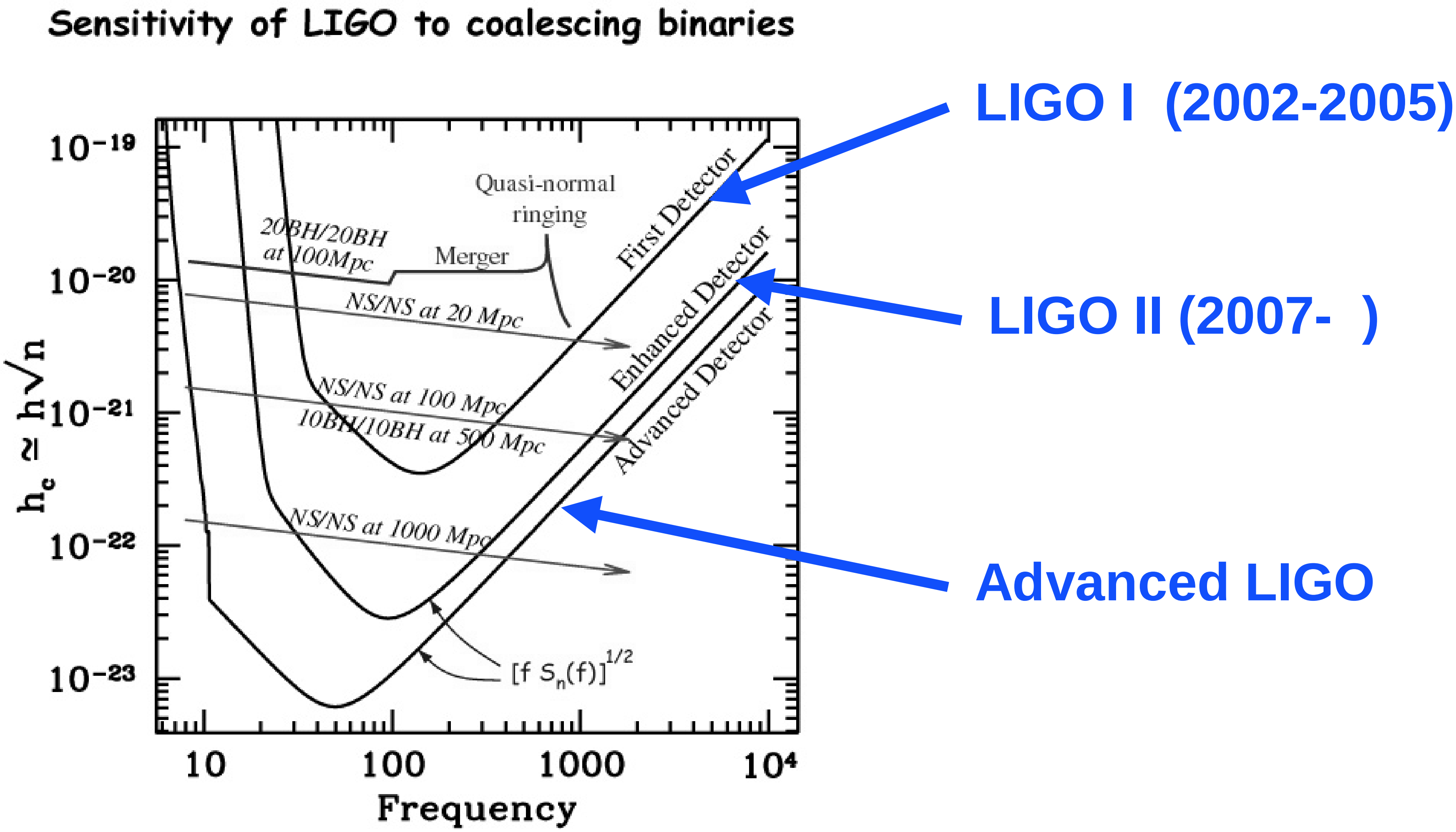


Significant Events

Hanford 2km interferometer	Single arm test complete installation complete interferometer locked	6/00 8/00 12/00
Livingston 4km interferometer	Input Optics completed interferometer installed interferometer locked	7/00 10/00 2/01
Coincidence Engineering Run (Hanford 2km & Livingston 4km)	Initiate Complete	7/01 7/02
Hanford 4km interferometer	All in-vacuum components installed interferometer installed interferometer locked	10/00 6/01 8/01
LIGO I Science Run (3 interferometers)	Initiate Complete (obtain 1 yr @ h ~ 10^{-21})	7/02 1/05

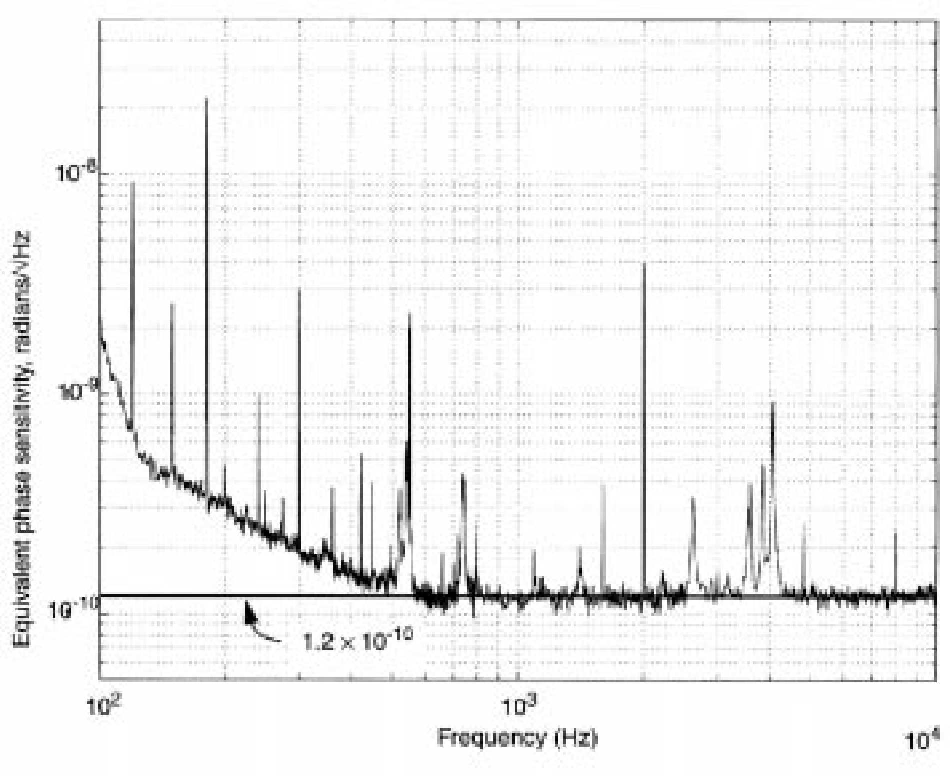
LIGO

astrophysical sources



Phase Noise

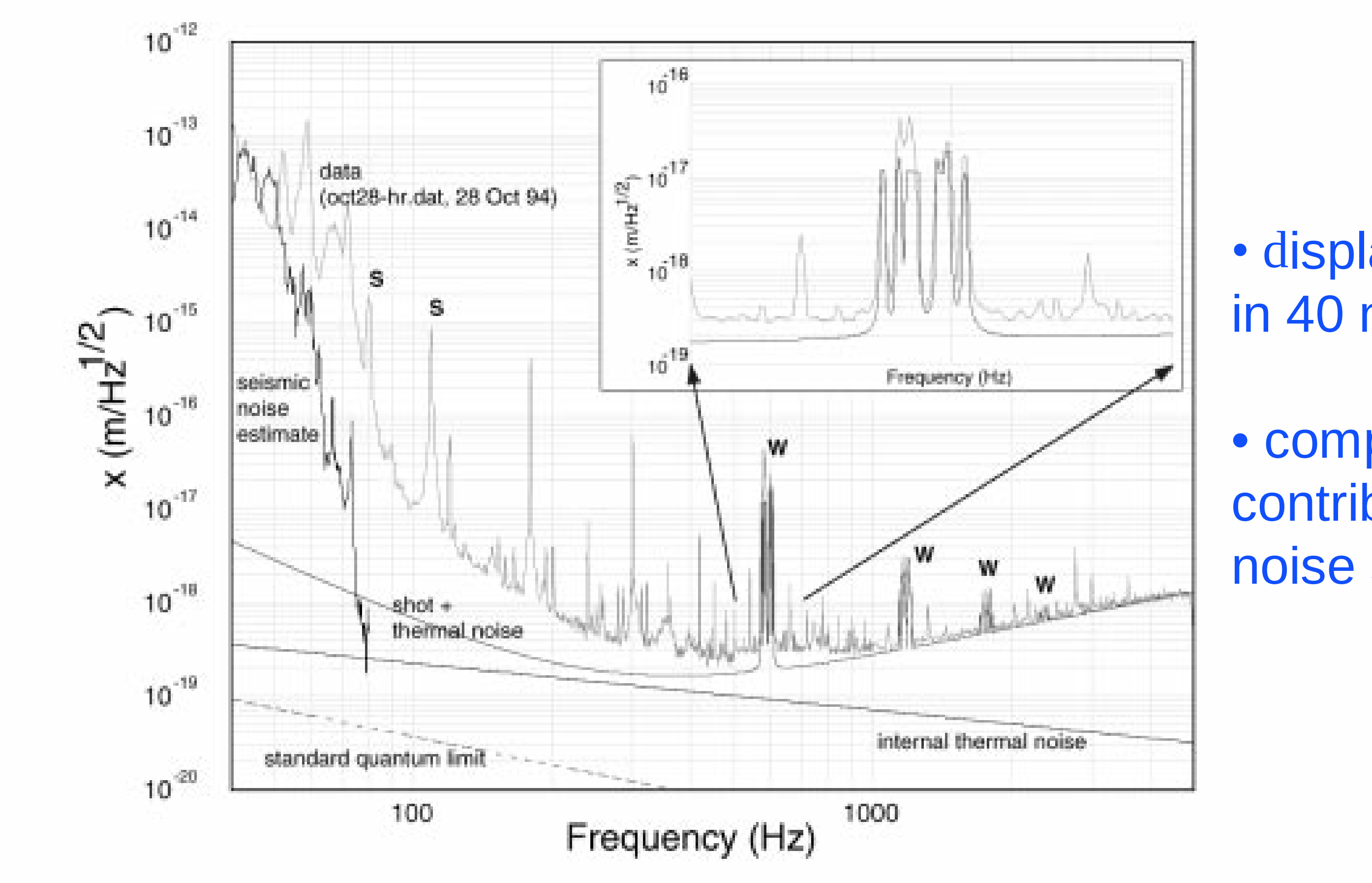
splitting the fringe



- spectral sensitivity of MIT phase noise interferometer
- above 500 Hz shot noise limited near LIGO I goal
- additional features are from 60 Hz powerline harmonics, wire resonances (600 Hz), mount resonances, etc

Noise Floor

40 m prototype



- displacement sensitivity in 40 m prototype.
- comparison to predicted contributions from various noise sources

Detection Strategy

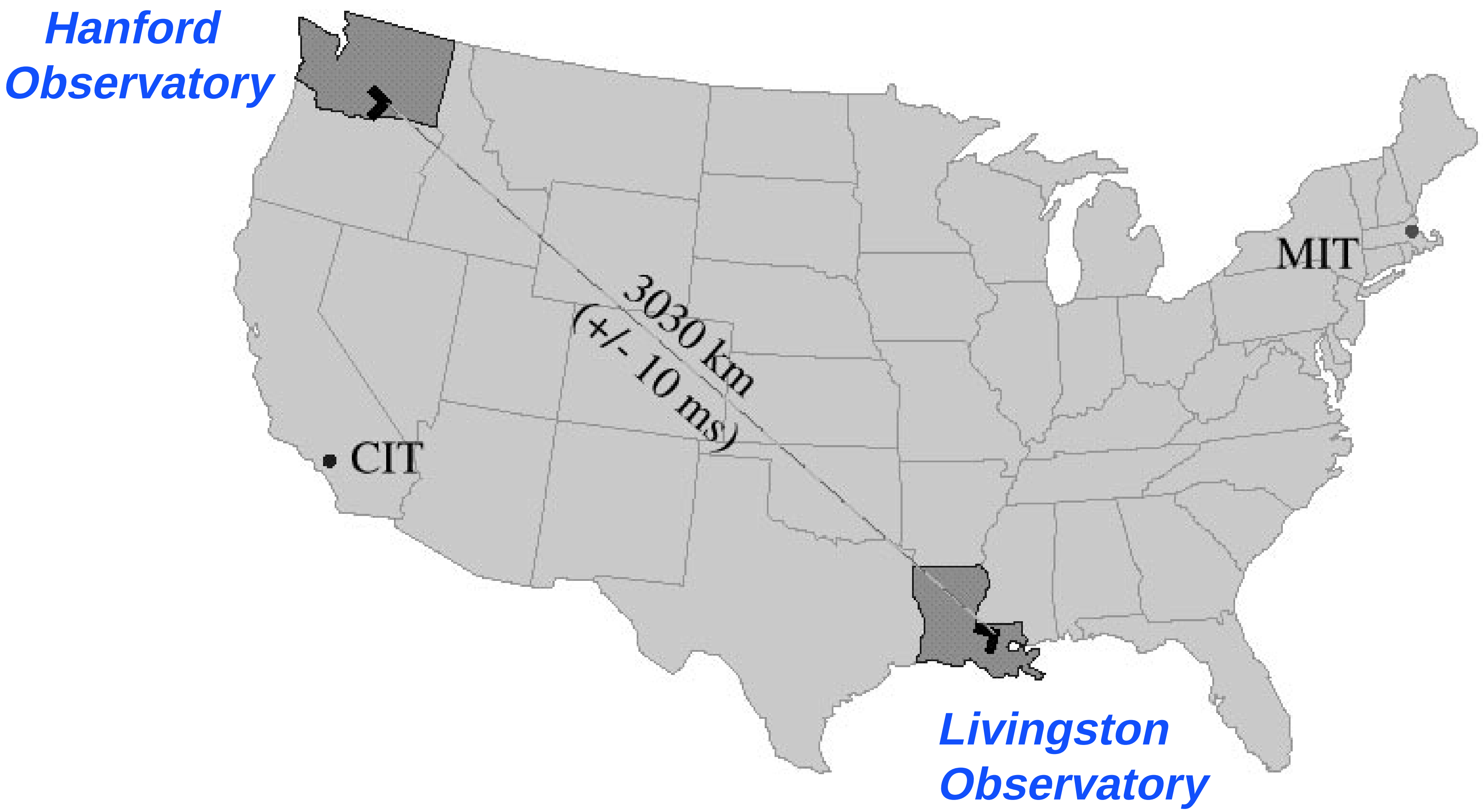
Coincidences

Two Sites - Three Interferometers

» Single Interferometer	non-gaussian level	~50/hr
» Hanford (Doubles)	correlated rate (x1000)	~1/day
» Hanford + Livingston	uncorrelated (x5000)	<0.1/yr

- **Data Recording (time series)**
  - » gravitational wave signal (0.2 MB/sec)
  - » total data (16 MB/s)
  - » on-line filters, diagnostics, data compression
  - » off line data analysis, archive etc
- **Signal Extraction**
  - » signal from noise (vetoes, noise analysis)
  - » templates, wavelets, etc

LIGO Sites


Hanford Observatory
3030 km
(+/- 10 ms)
MIT
CIT
Livingston Observatory

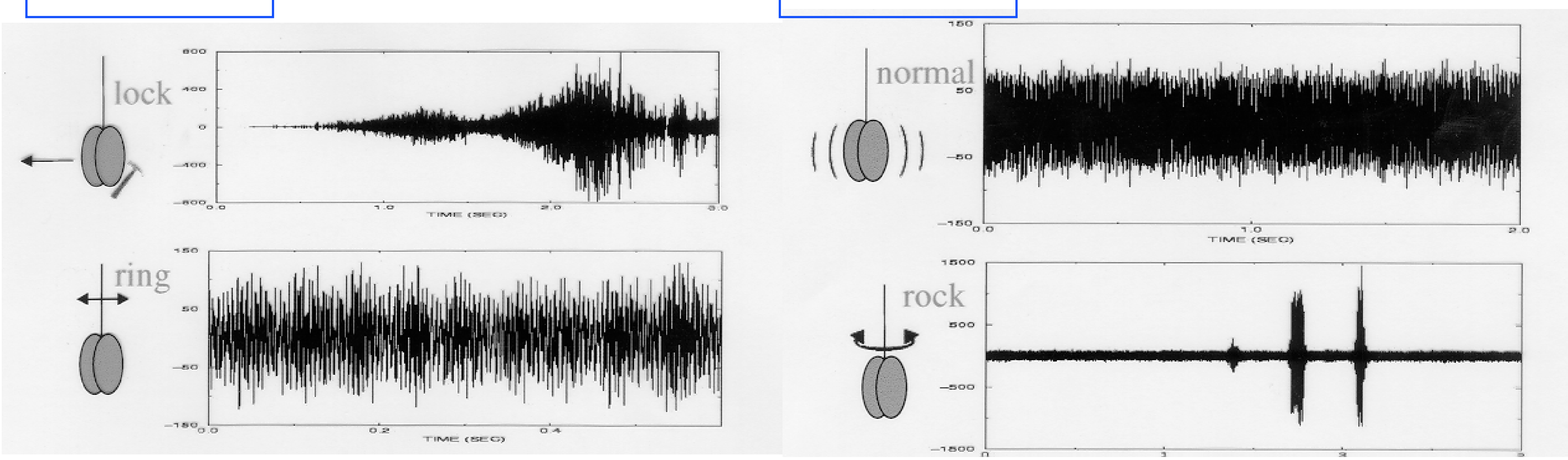
Interferometer Data

40 m

Real interferometer data is UGLY!!!

(Gliches - known and unknown)

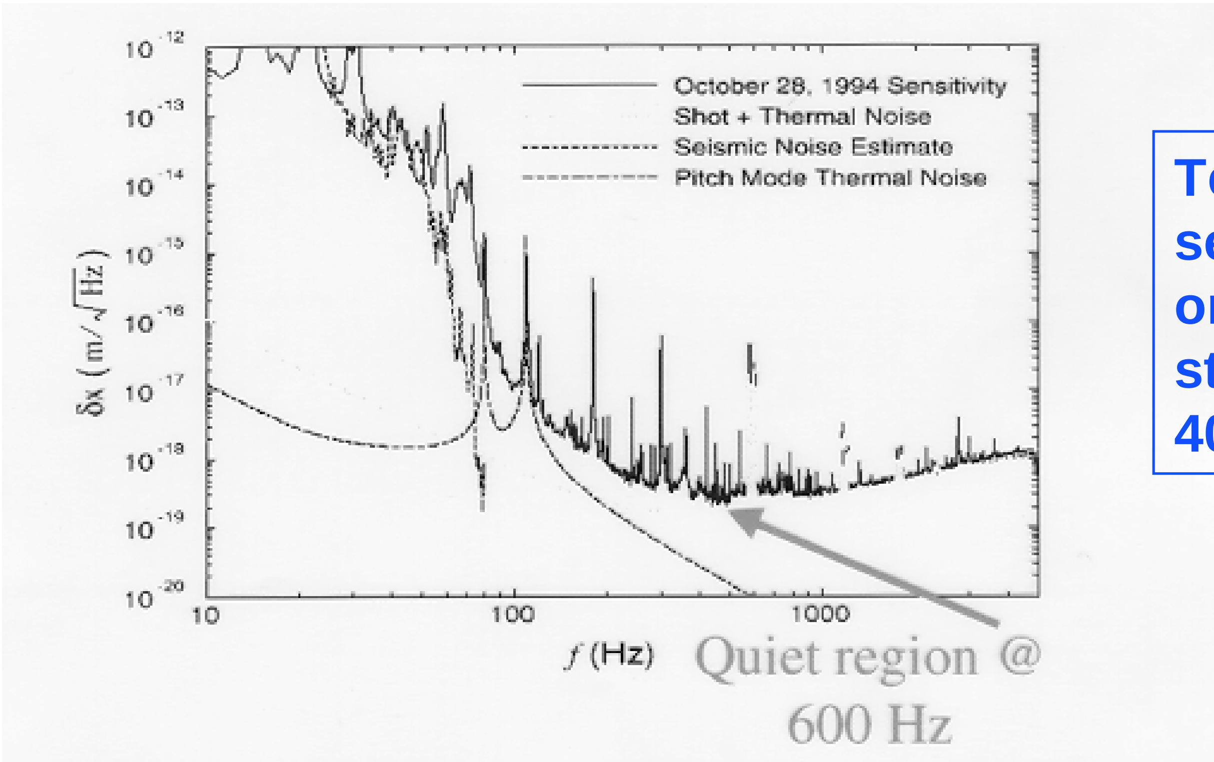
LOCKING **NORMAL**



RINGING **ROCKING**

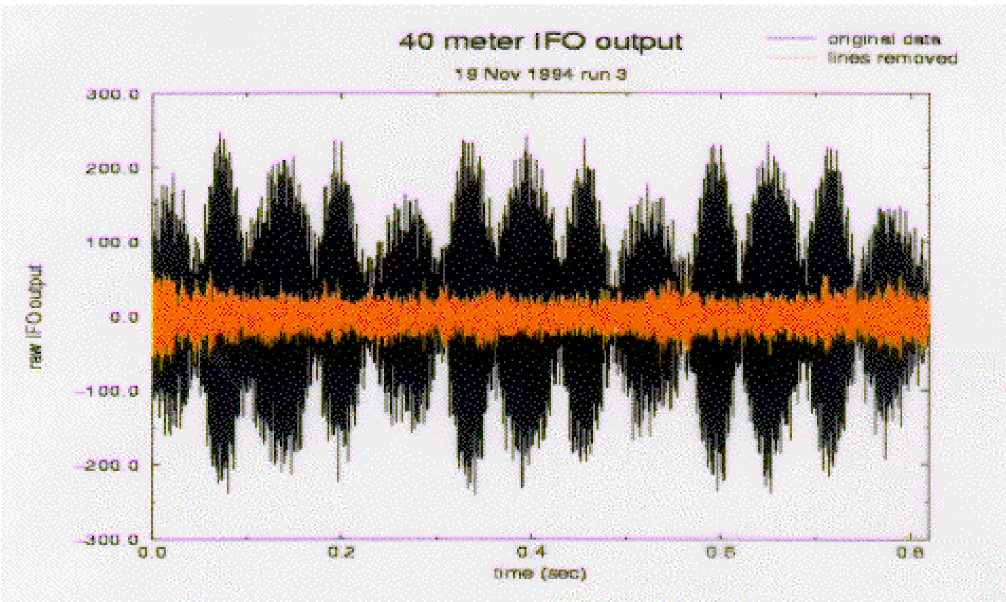
The Problem

How much does real data degrade complicate the data analysis and degrade the sensitivity ??

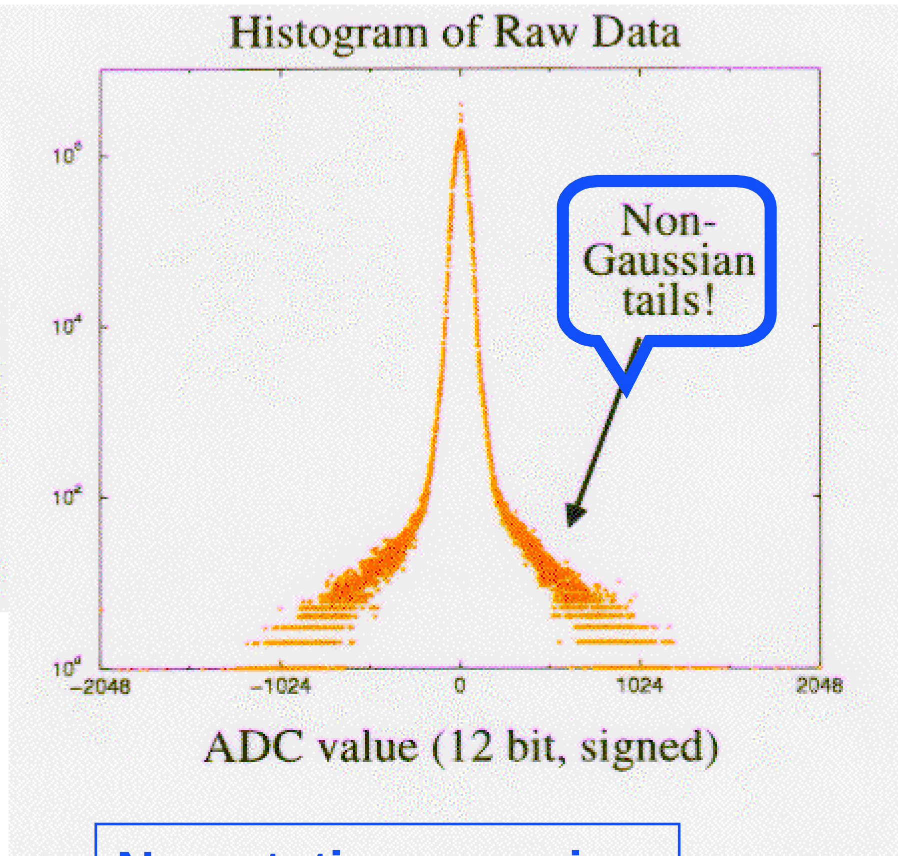


Test with real data by setting an upper limit on galactic neutron star inspiral rate using 40 m data

"Clean up" data stream

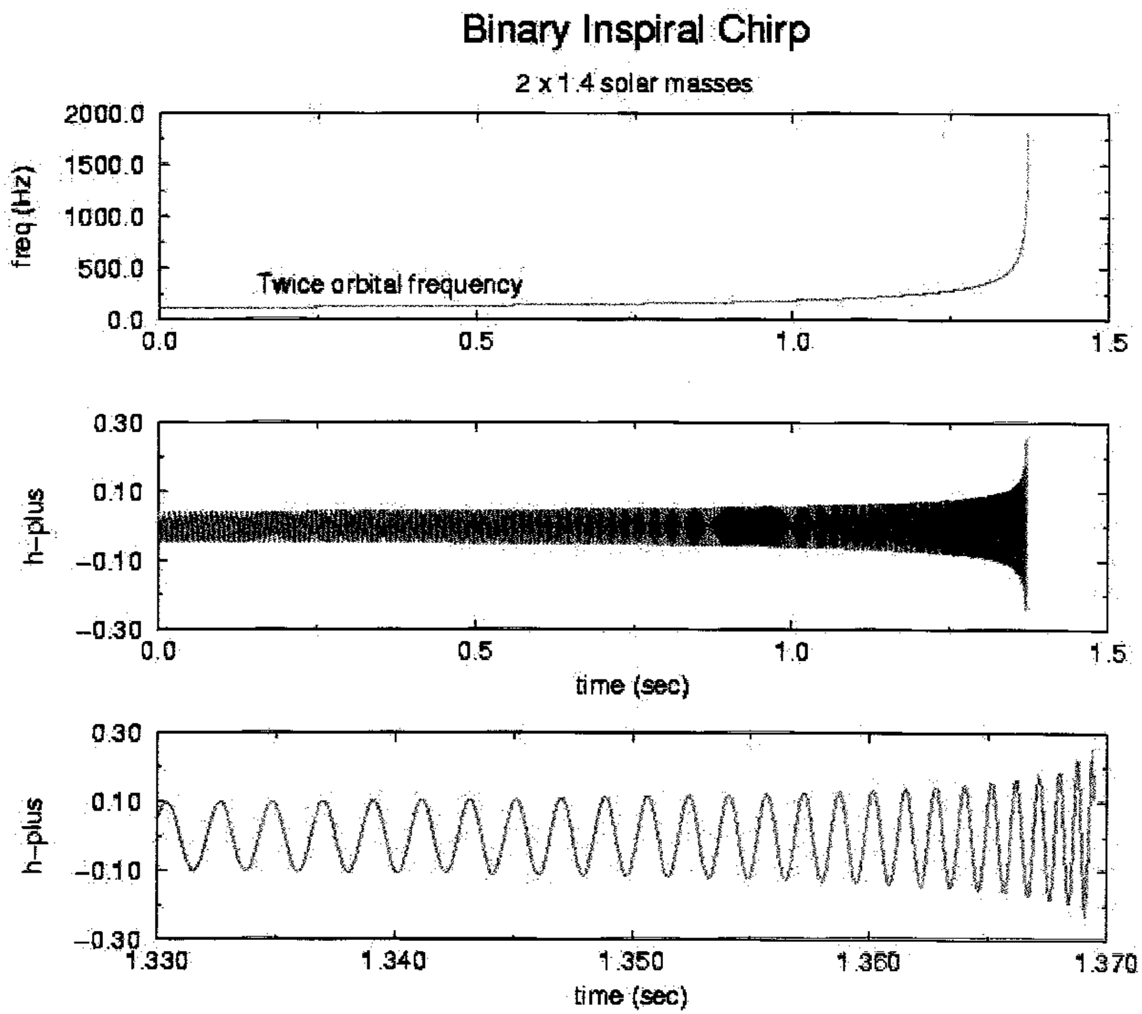


Effect of removing sinusoidal artifacts using multi-taper methods



Non stationary noise
Non gaussian tails

Inspiral 'Chirp' Signal



Template Waveforms

"matched filtering"
687 filters

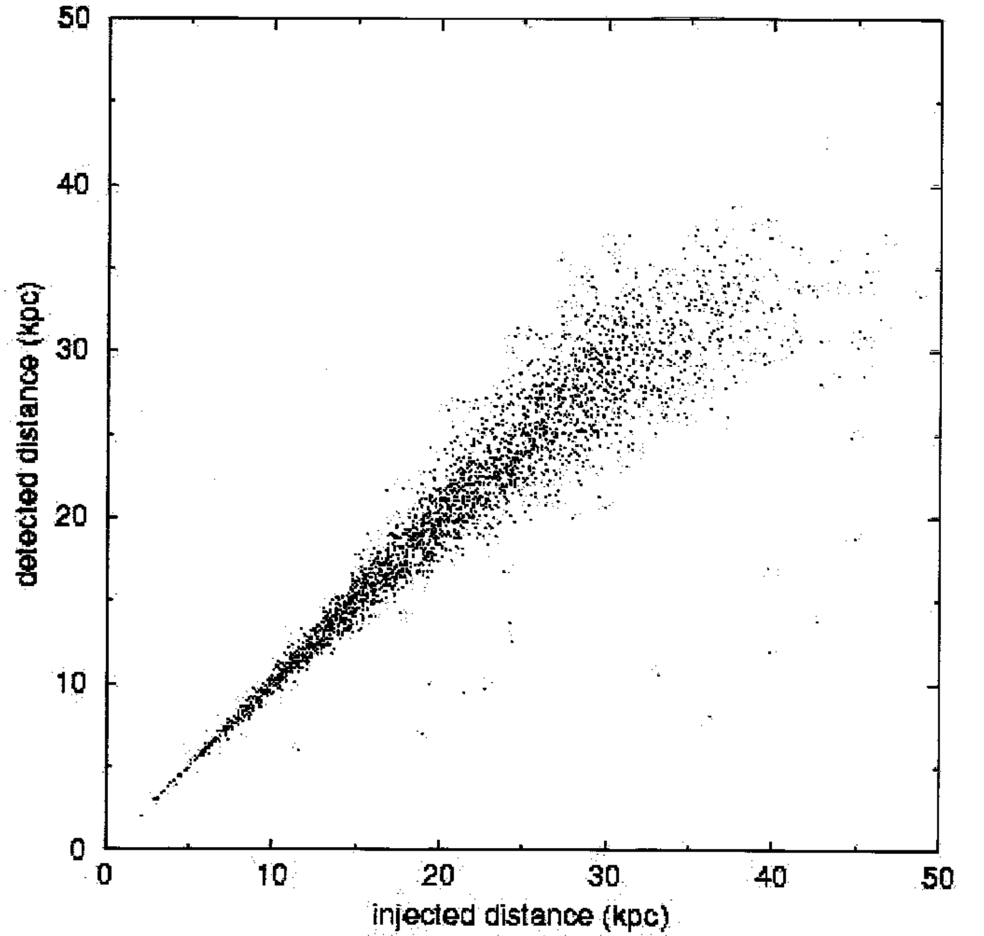
44.8 hrs of data
39.9 hrs arms locked
25.0 hrs good data

sensitivity to our galaxy
$h \sim 3.5\ 10^{-19}\ mHz^{-1/2}$
expected rate ~10^{-6}/yr

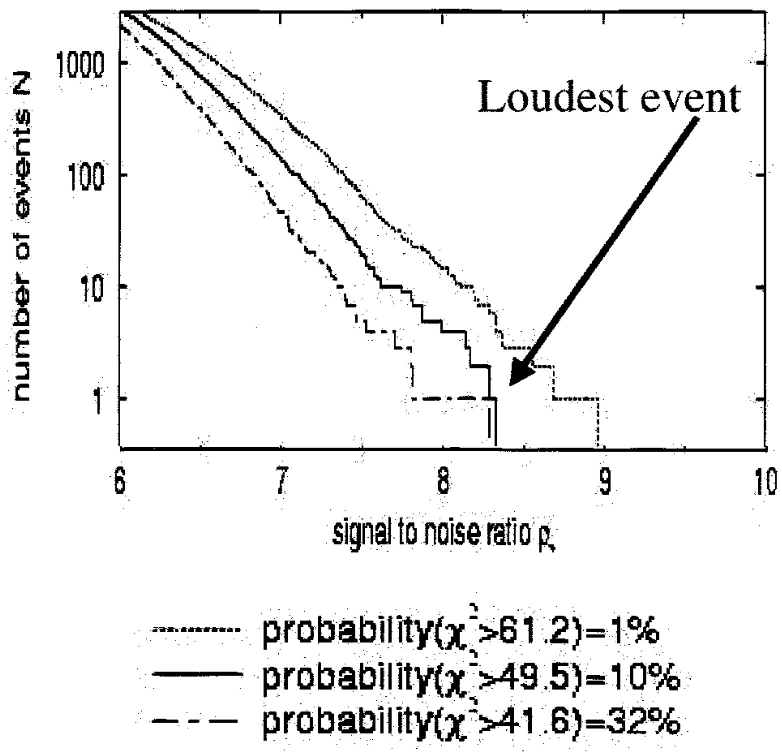
Detection Efficiency

• Simulated inspiral events provide end to end test of analysis and simulation code for reconstruction efficiency

• Errors in distance measurements from presence of noise are consistent with SNR fluctuations



Setting a limit



Upper limit on event rate can be determined from SNR of 'loudest' event

Limit on rate:

R < 0.5/hour with 90% CL

ε = 0.33 = detection efficiency

An ideal detector would set a limit:

R < 0.16/hour

Conclusions

- LIGO I construction complete
- LIGO I commissioning and testing ‘on track’
- Interferometer characterization underway
- Data analysis schemes are being developed, including tests with 40 m data