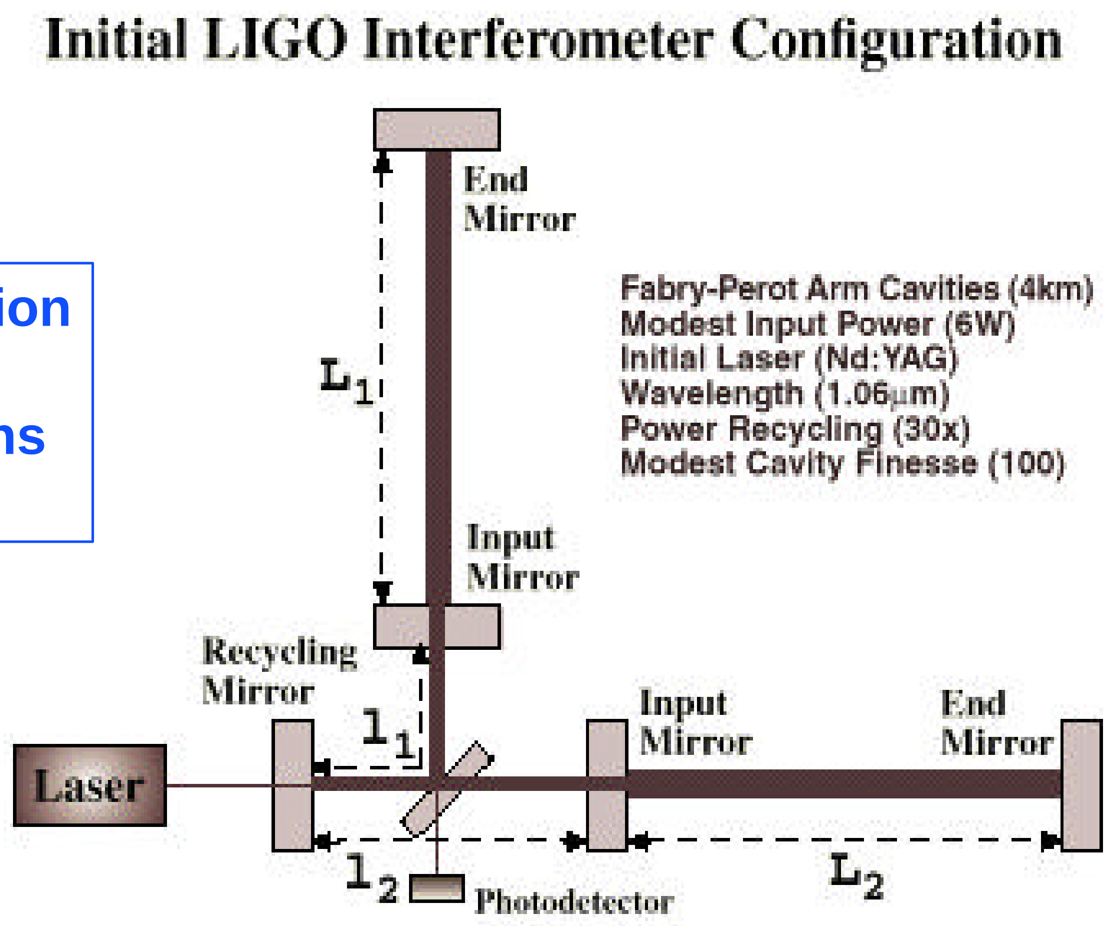
Status of LIGO

Mark Barton

Aspen Winter Conference
on Gravitational Waves and Their Detection

LIGO I
interferometer

- **LIGO I configuration**
- **Science run begins in 2002**

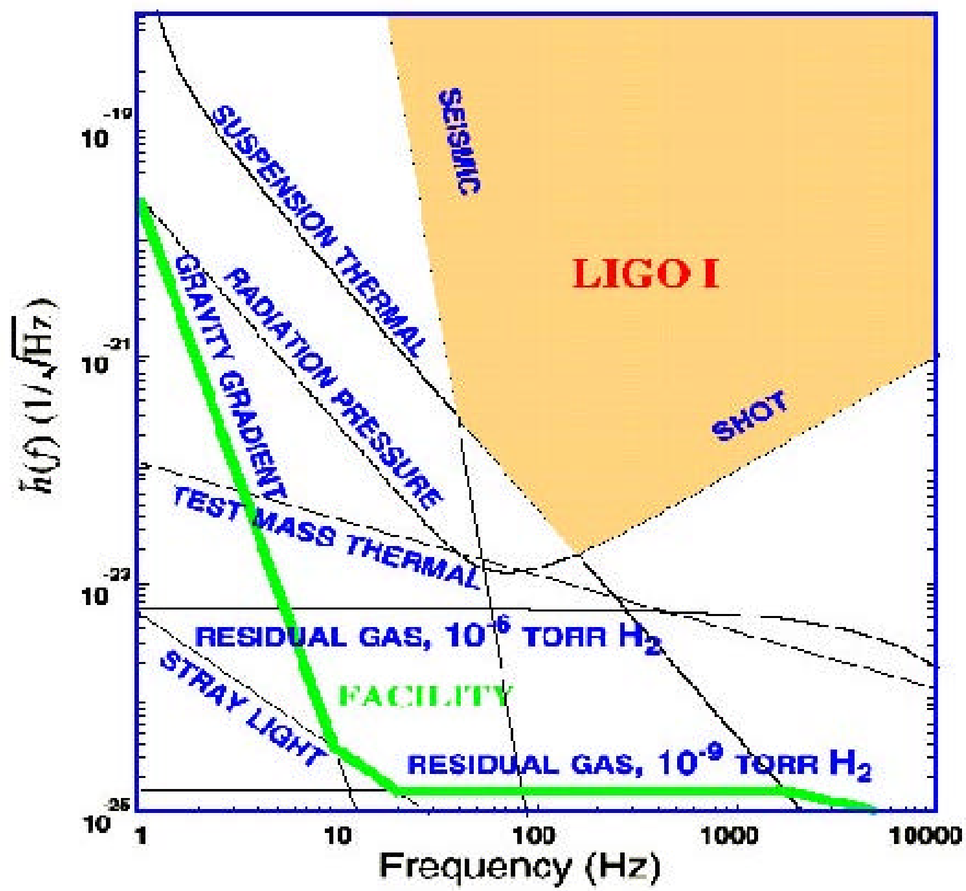


LIGO I

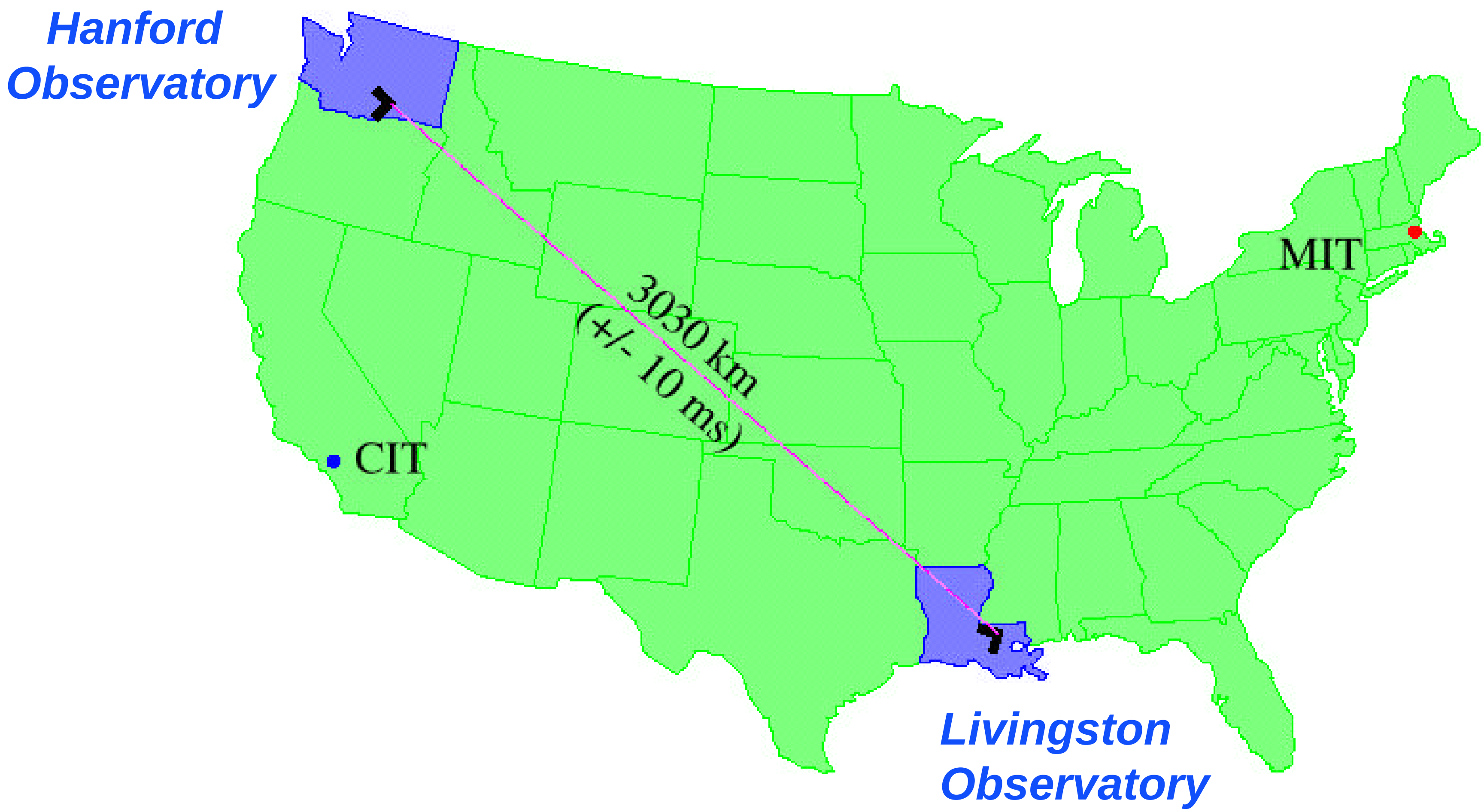
the noise floor

- **Interferometry is limited by three fundamental noise sources**
  - **seismic noise at the lowest frequencies**
  - **thermal noise at intermediate frequencies**
  - **shot noise at high frequencies**

- **Many other noise sources lurk underneath and must be controlled as the instrument is improved**



LIGO Sites


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

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**

Interferometers
international network

LIGO (Washington)

LIGO (Louisiana)

Construction Project
status

- 98% complete

- construction project will finish on the budget & schedule

- Hanford buildings complete
  - » last laboratory building
    - – contract A&E design

- Livingston complete
  - » last laboratory building
    - – contracting construction

LIGO Facilities

Beam Tube Enclosure

- minimal enclosure
- reinforced concrete
- no services

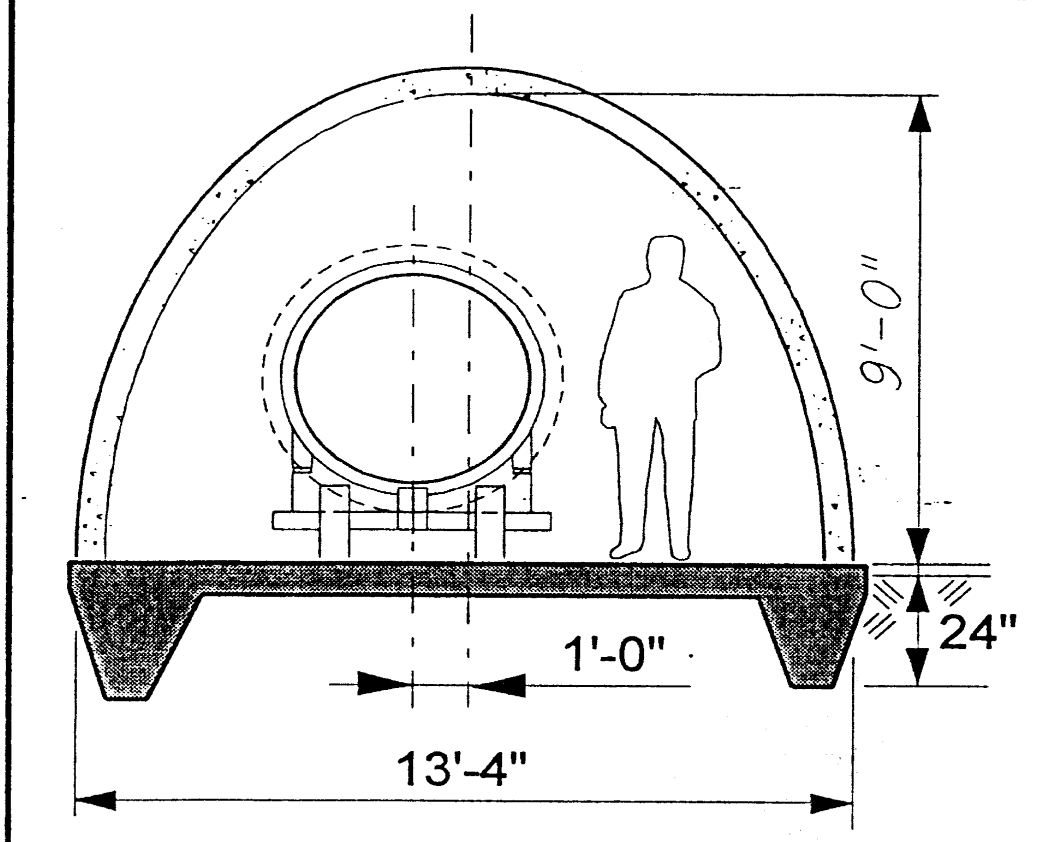
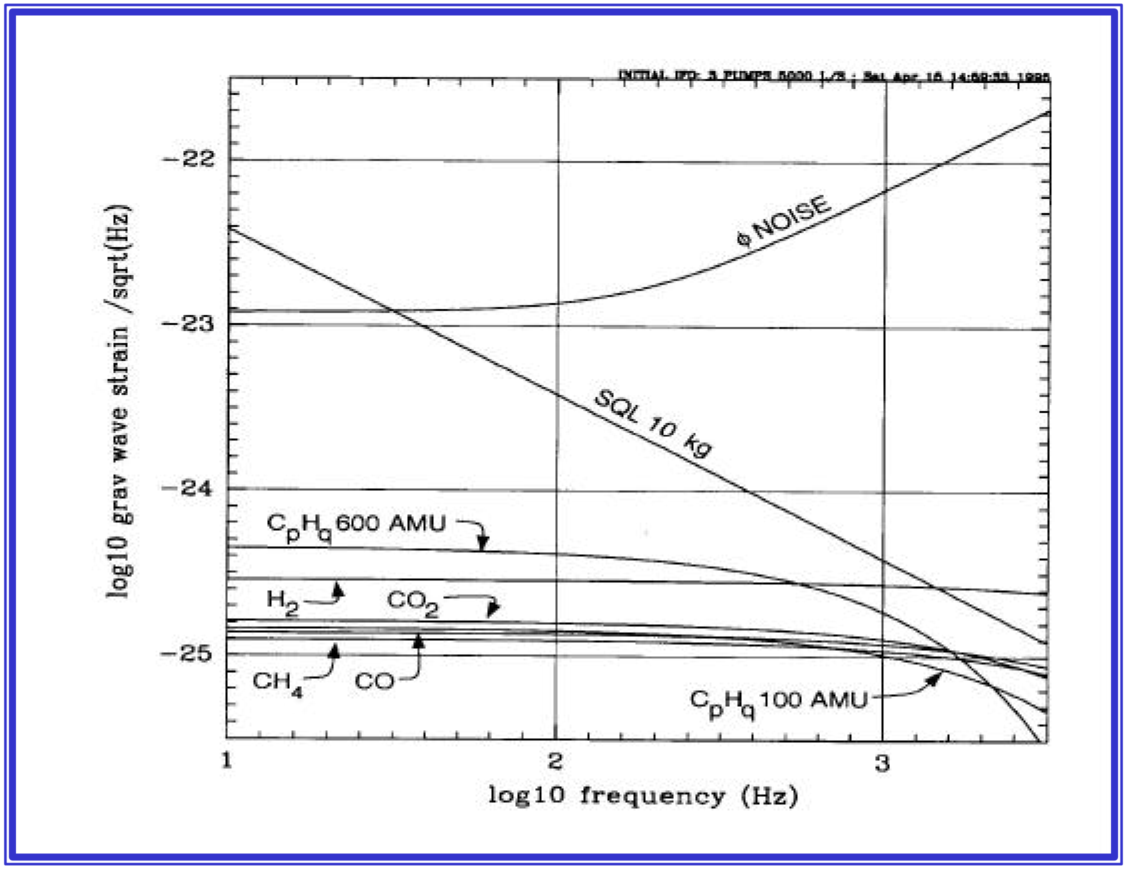


Figure 2.1-1 -- Cross Section of Design Baseline at Hanford

Beam Tube Bakeout



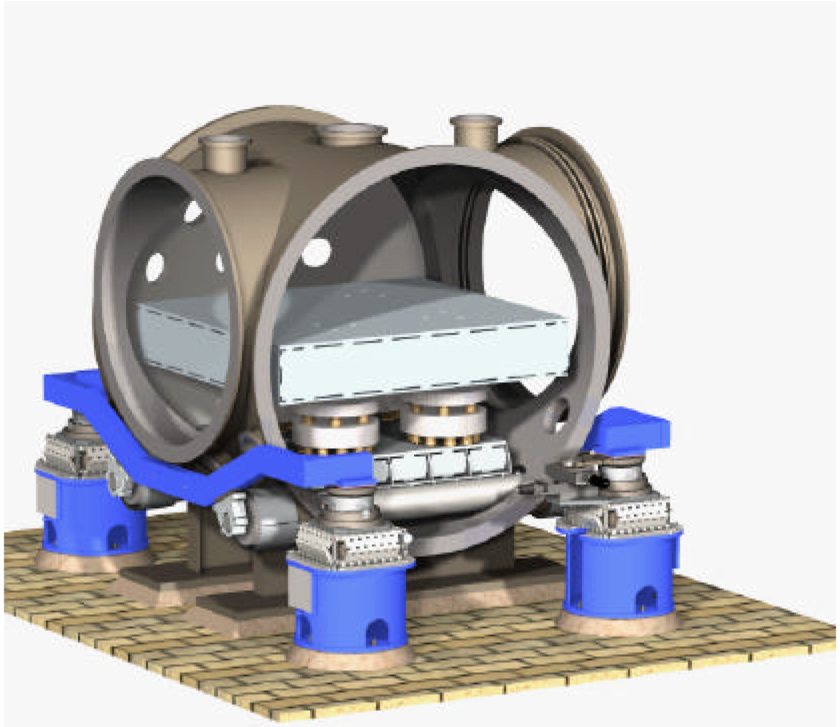
LIGO

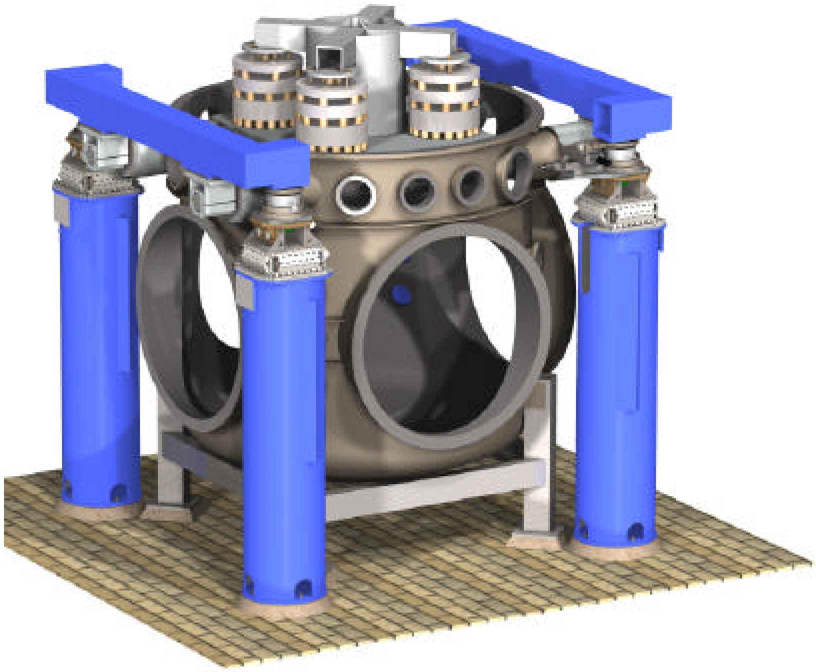
vacuum equipment

Vacuum Chambers

Vibration Isolation Systems

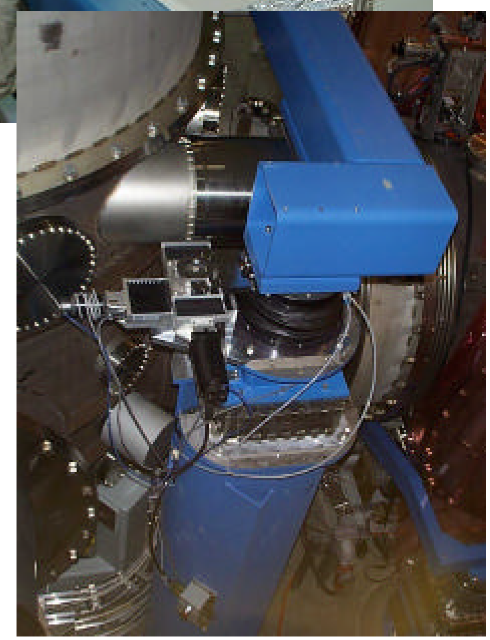
» **Reduce in-band seismic motion by 4 - 6 orders of magnitude**
» **Compensate for microseism at 0.15 Hz by a factor of ten**
» **Compensate (partially) for Earth tides**





Seismic Isolation Systems

Support Tube Installation



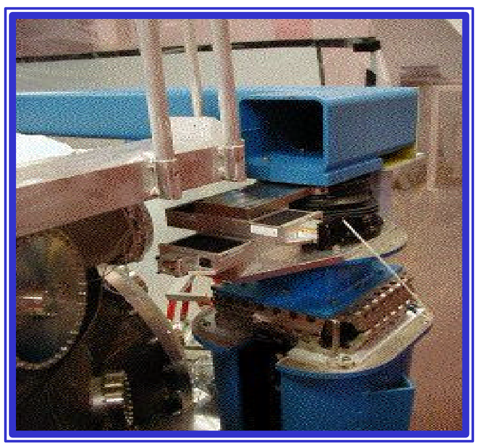
Stack Installation

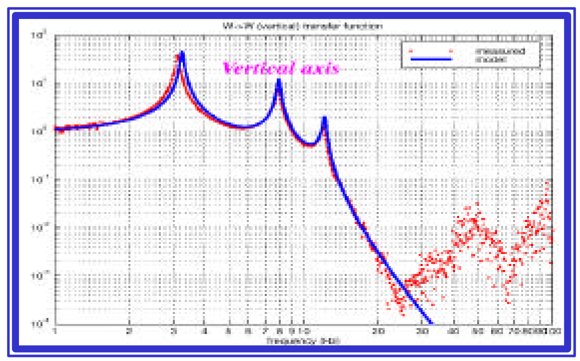
Coarse Actuation System

Seismic Isolation

constrained layer damped springs

Seismic Isolation

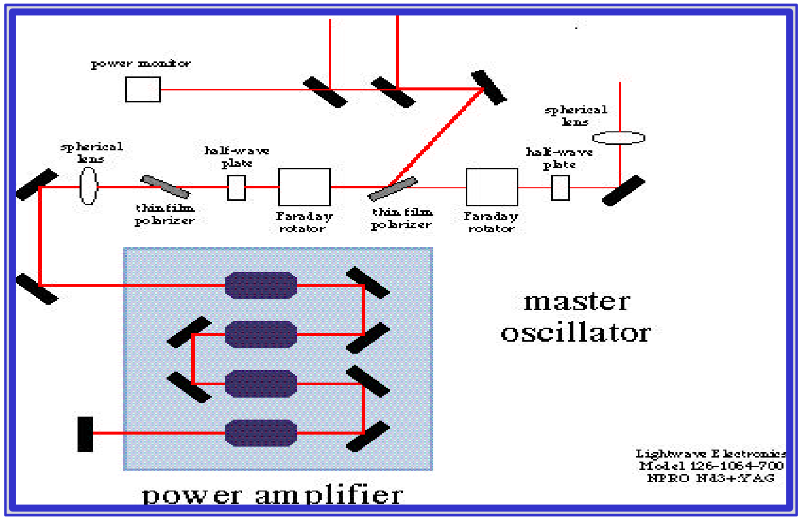


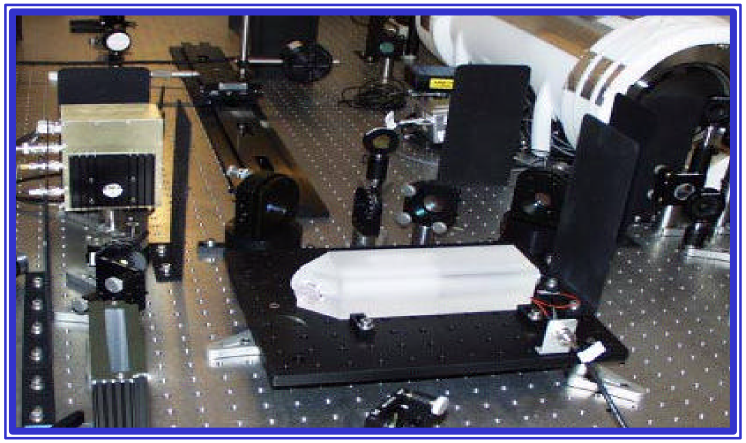


LIGO

Laser

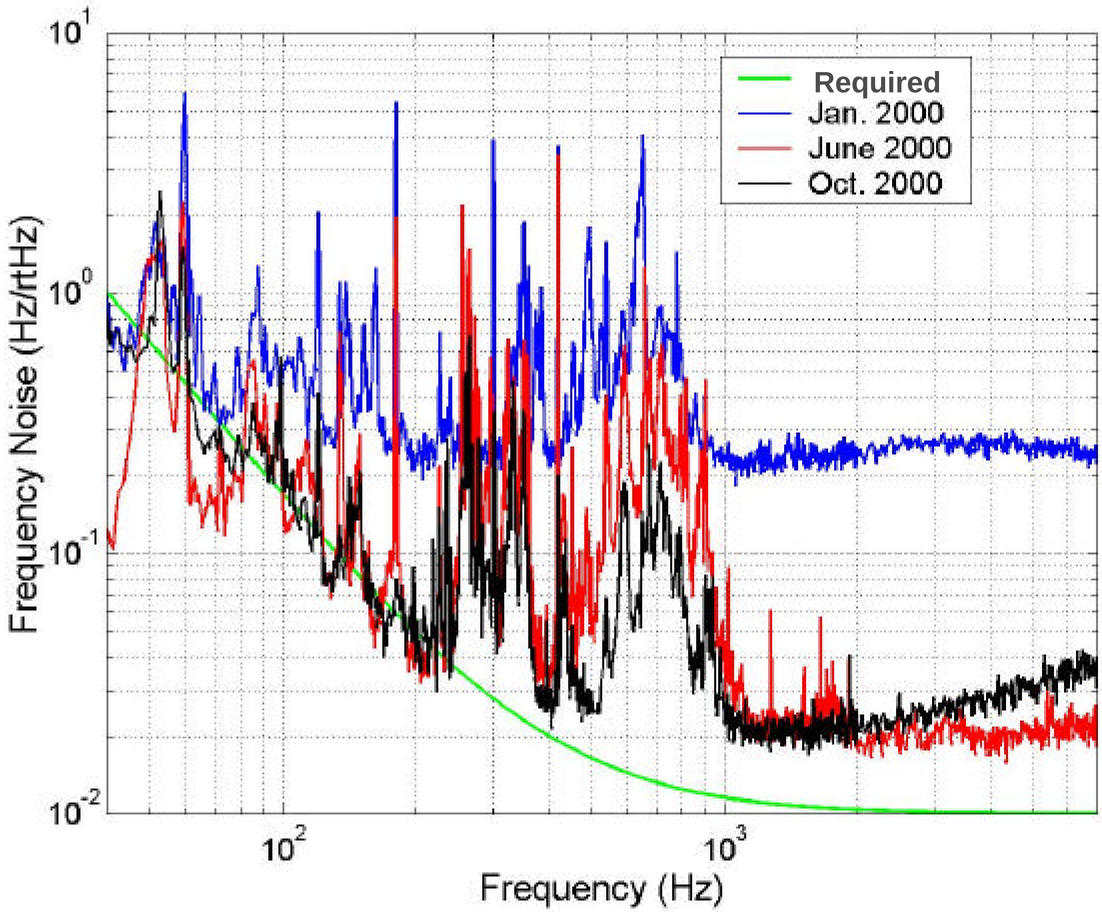
- **Nd:YAG**
- **1.064 μm**
- **Output power > 8W in TEM00 mode**





Improvements in Laser Performance

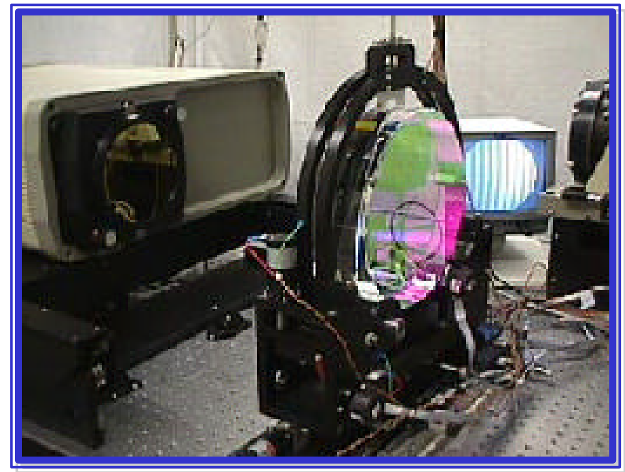
- Laser stability an important contributor to LIGO sensitivity
- Steady improvement in laser noise performance
  - » electronics
  - » acoustics
  - » vibrations

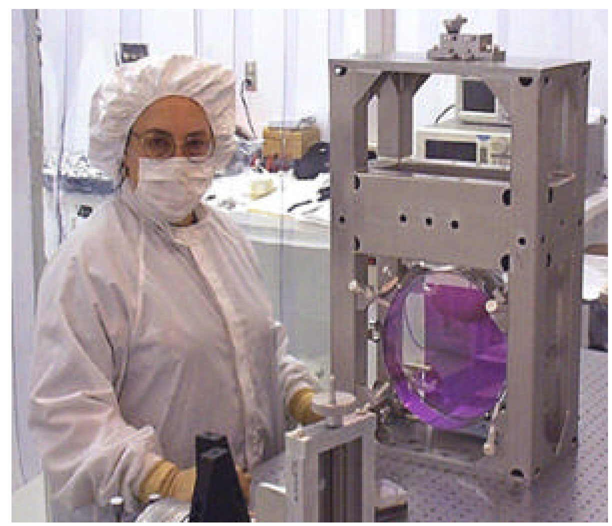


Optics

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)**

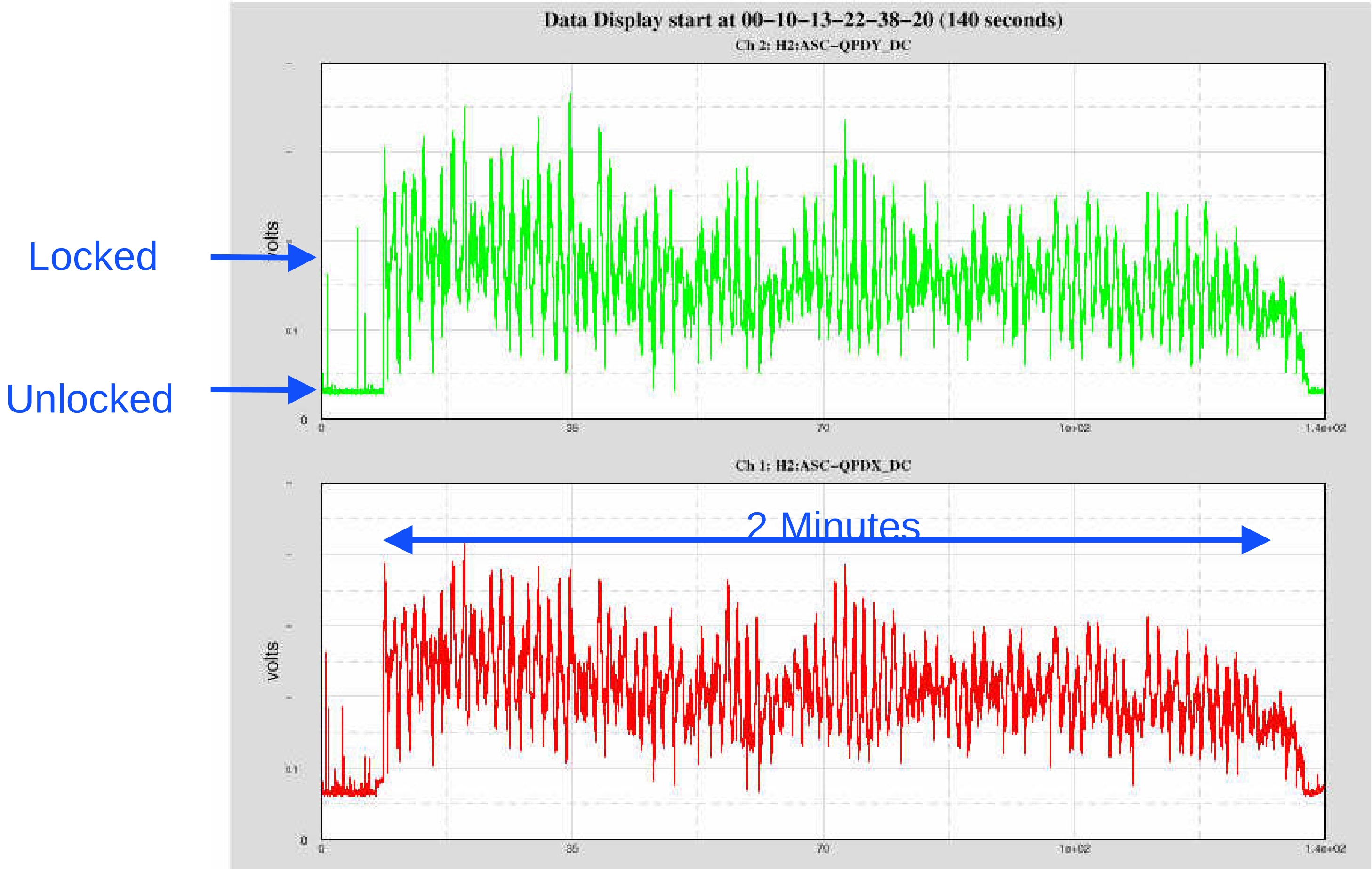




Suspensions

Full Interferometer Locking

- Still a bit tenuous…….



Hanford Commissioning Time Line

Configurations and Lock Periods

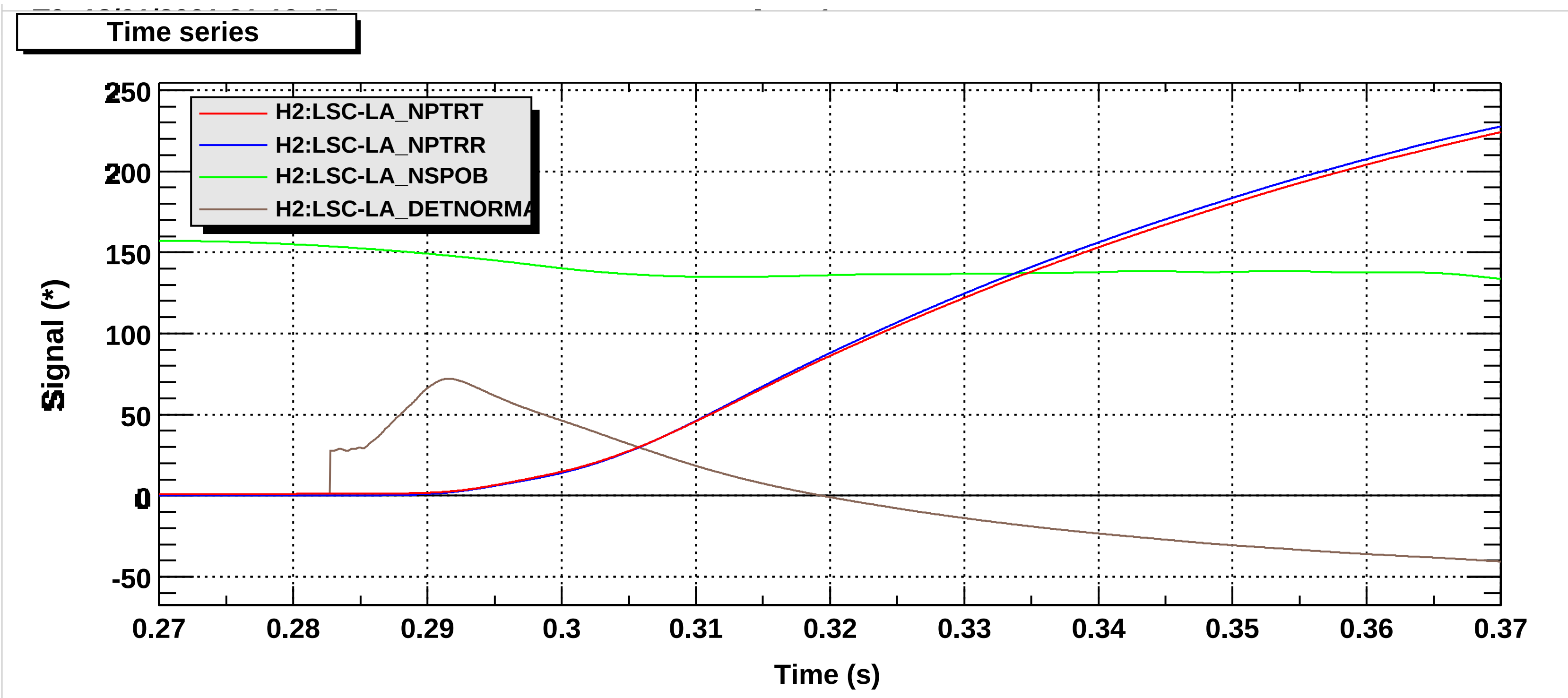
- 11/99 - Beam down 2 km arm (Y)
- 12/9/99 - 0.2 s lock of Y arm cavity
- 1/14/00 - 2 s lock of Y arm
- 1/19/00 - 60 s lock of Y arm
- 1/21/00 - 5 min lock of Y arm
- 2/12/00 - 18 min lock of <u>X</u> arm
- 3/4/00 - 90 min lock of X arm
- 3/26/00 - 10 hr lock of X arm
- vent for installation
- 7/00 - lock of power-recycled Michelson
- 8/00 - lock of PRM + one arm
- 10/00 - 2 min full lock
- 11/00 - “E2” engineering run (1 arm only)
- 1/01 - 40 min full lock

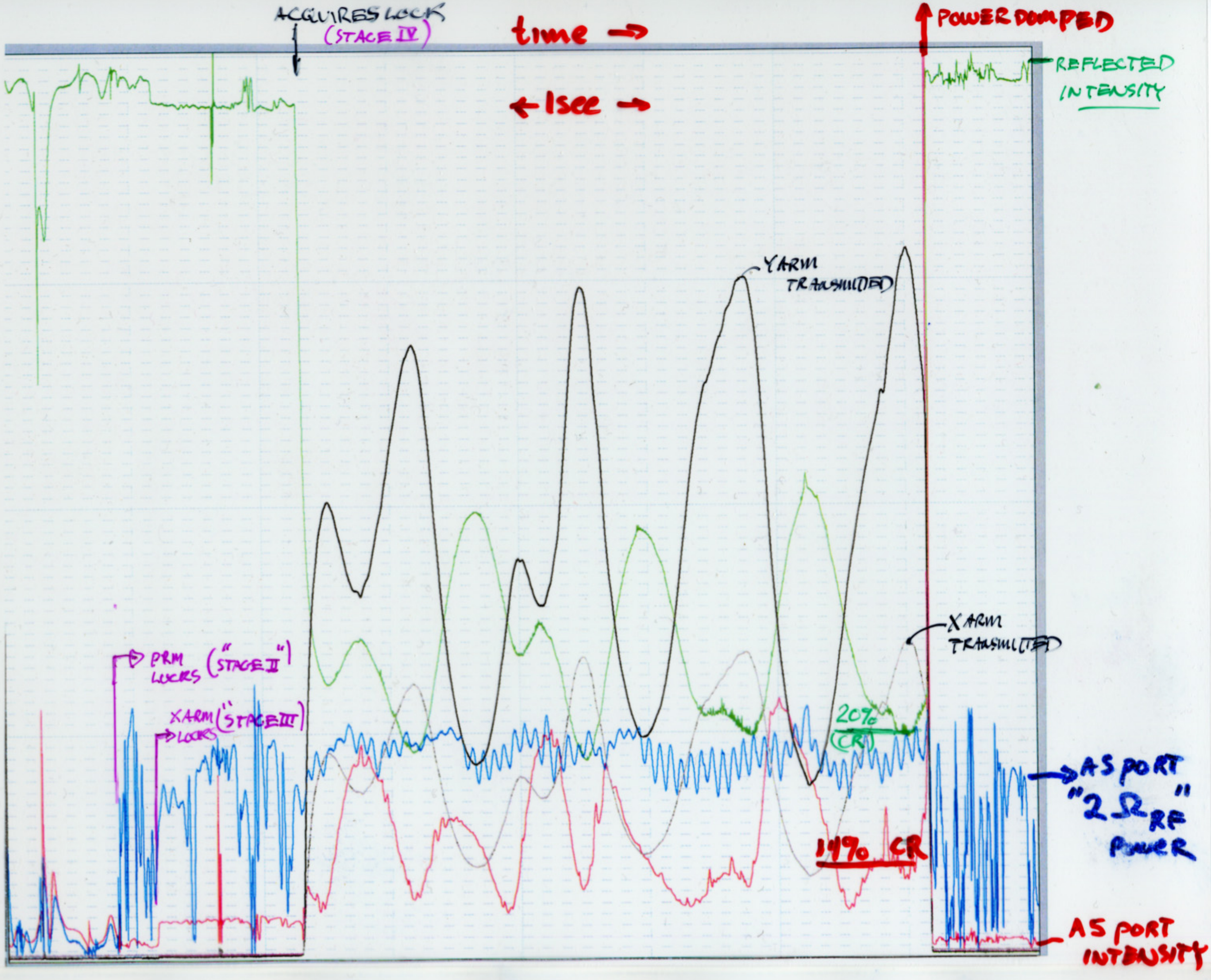
Lock Sequence

- Well-defined series of stages:
  - Phase I - No resonance
  - Phase II - Sidebands resonant in PRM
  - Phase III - Sidebands resonant in PRM, carrier resonant in one arm
  - Phase IV - Sidebands resonant in PRM, carrier resonant in both arms
- Progress from stage to stage automated
  - Software recognises state of IFO based on estimators
  - Adjusts control parameters to move from state to state
  - Estimators derived from E2E modelling, improved with experience

Control Issues

- Key to full lock is managing sign change of determinant of control matrix
  - recognise approaching zero using estimators from modelling
  - disable selected servos temporarily, reenable with reversed sign



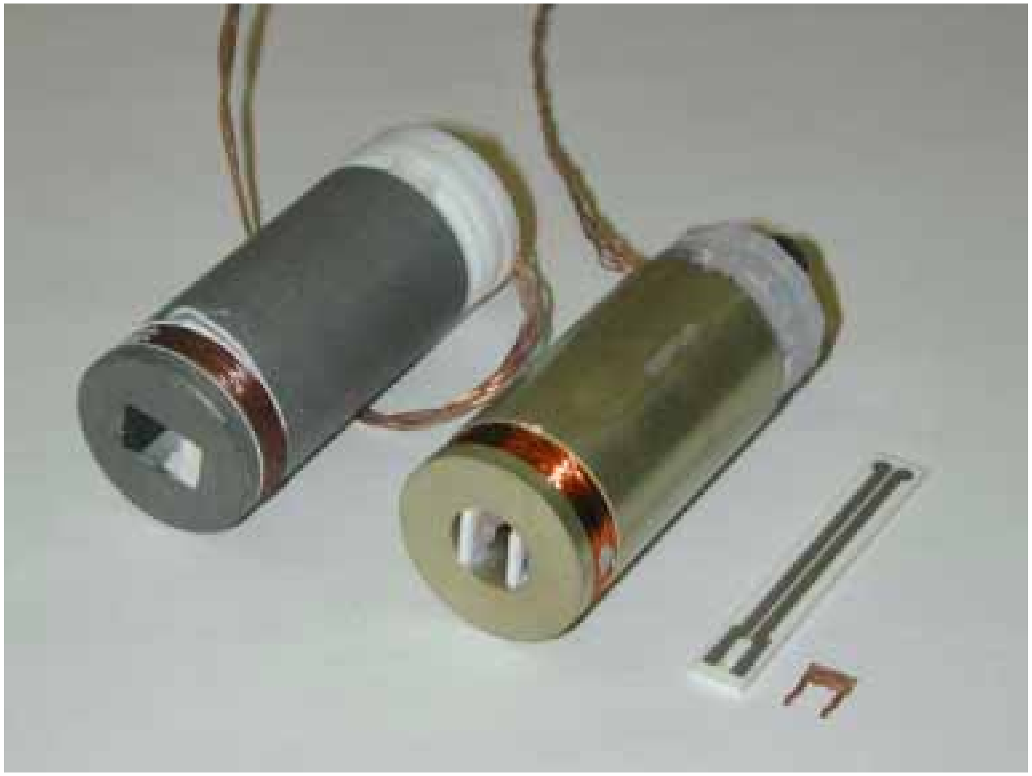

ACQUIRES LOCK
(STAGE IV)
time →
POWER DUMPED
REFLECTED INTENSITY
← 1 sec →
YARM TRANSMITTED
XARM TRANSMITTED
PRM LOCKS ("STAGE II")
XARM LOCKS ("STAGE III")
20% CR
14% CR
AS PORT "2 Ω RF" POWER
AS PORT INTENSITY

Pitch/Yaw Problem

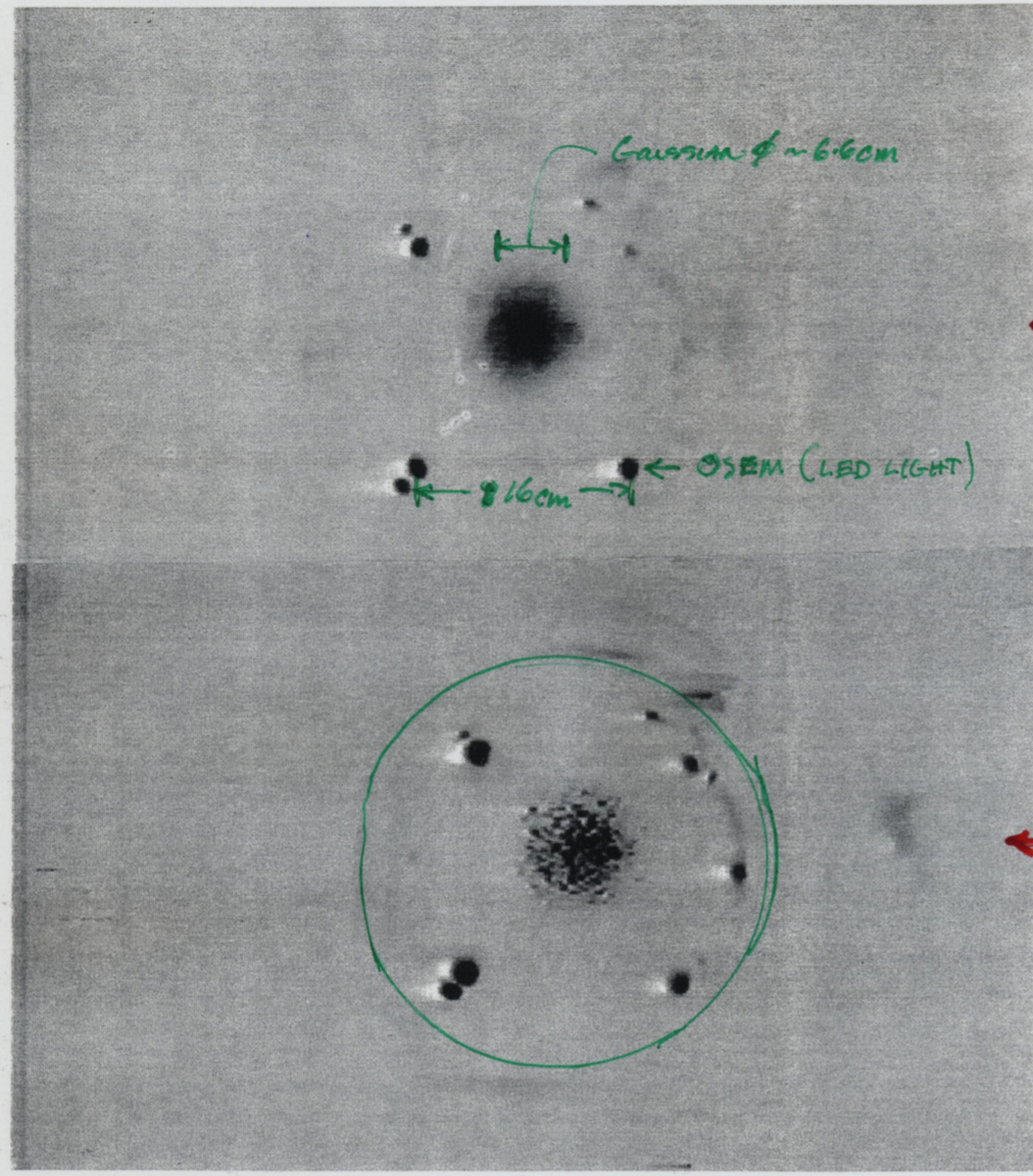
- ≈0.5-1 Hz oscillations in cavity power due to poor alignment control
- Interference problem with shadow sensors for local control
  - shadow sensors use IR LED/PD
  - great when IFO beam was to be green (Argon) - now a problem
  - redesign with different LED/PD and modulation for LHO 4k, retrofit to 2k, LLO
  - in the meantime, use very low gain
- Global alignment control only just being implemented
  - - wavefront sensors recently added
  - improves locking time from seconds to many minutes

New OSEMs

- New LED/PD
- Still IR but clear of 1064 nm
- Smoother coating (ZrN)
- Better PAM screw
- Better wire routing
- Simpler body design
- New modulated electronics
- Install in Hanford 4km, retrofit to 2 km and Livingston



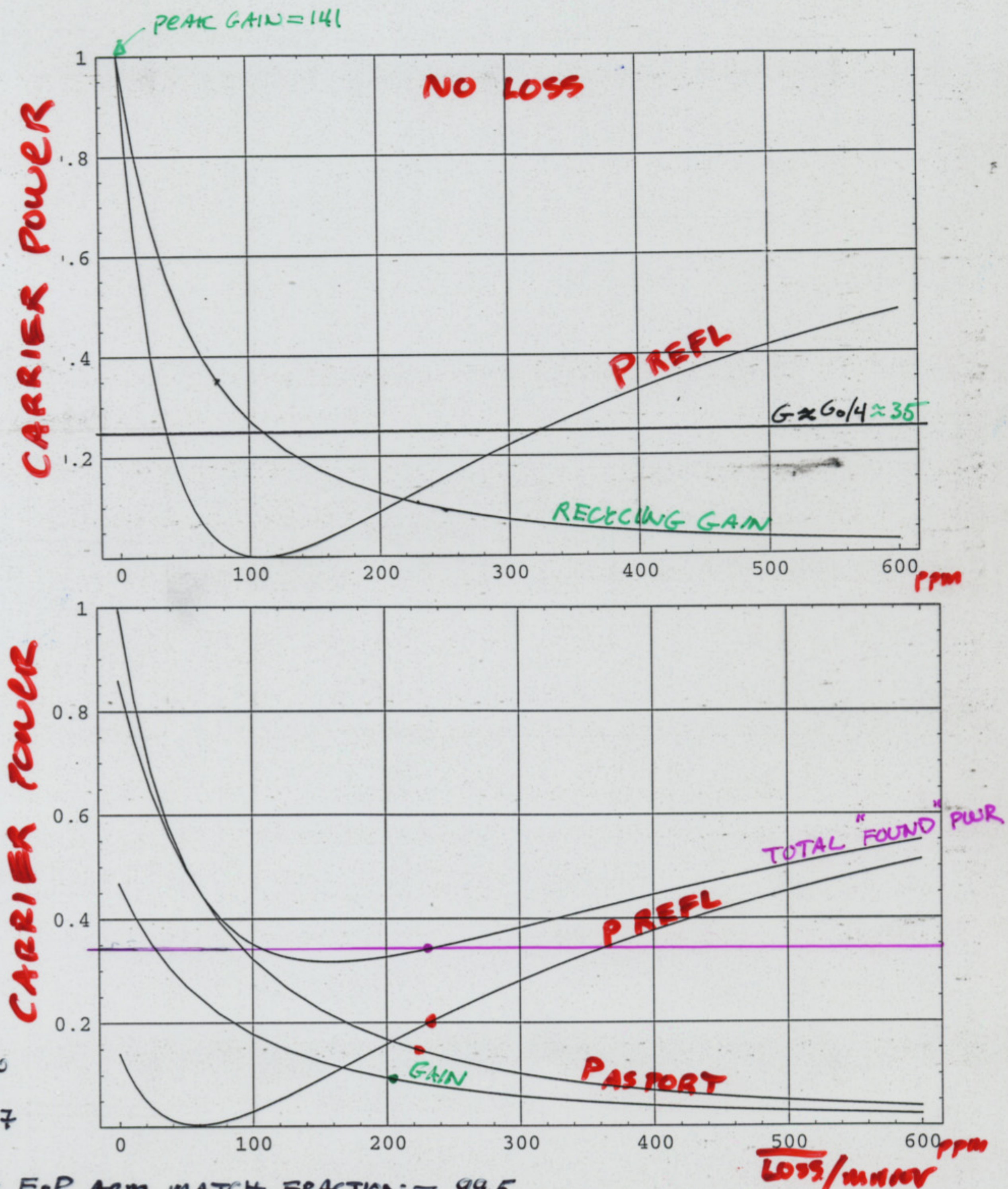
~JAN 22 '01 FULL LOCK LHO 2K SPOOL VIEWS OF ETMS



ETM X

ETM Y

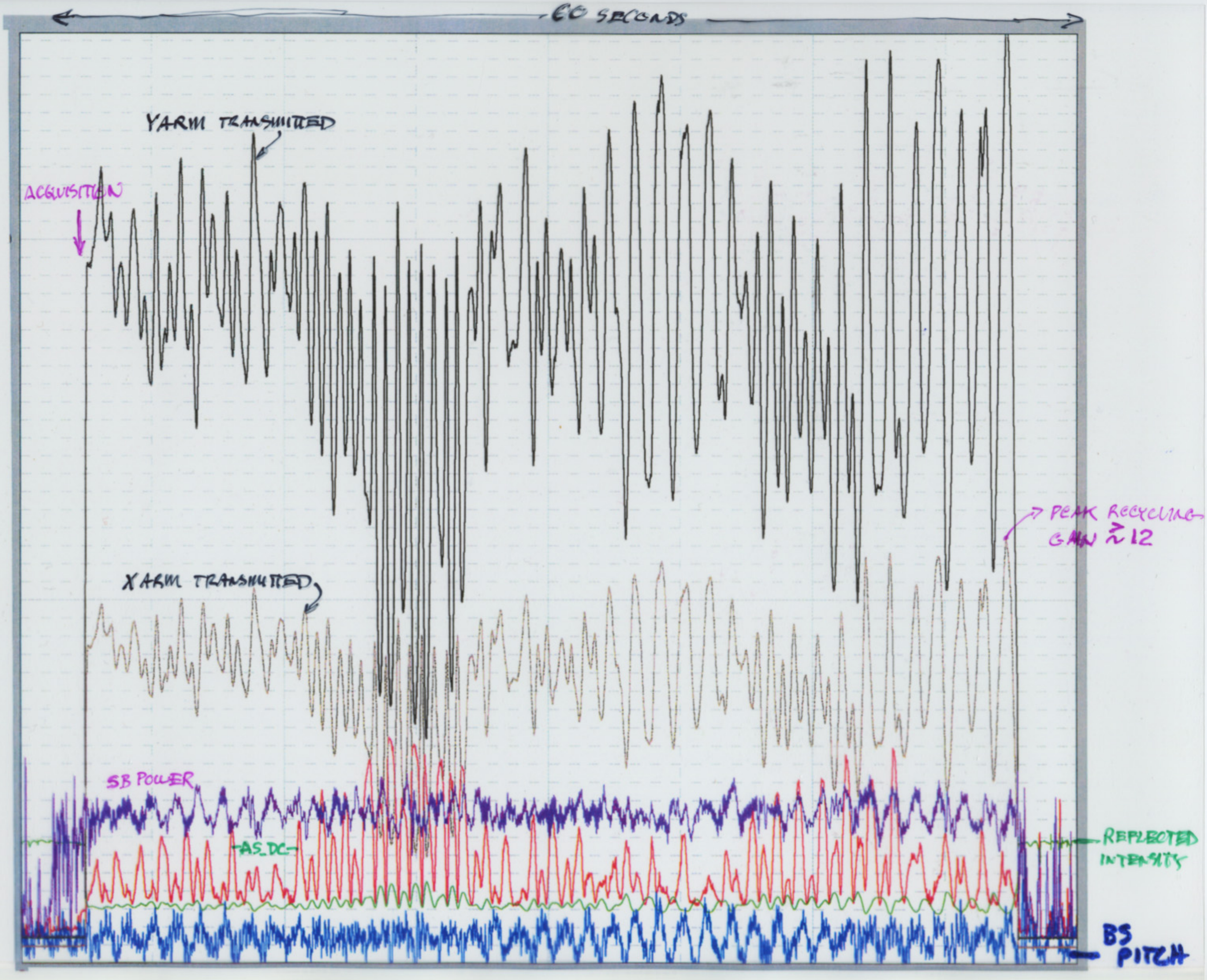
CONTAMINATION OR COATING FLAWS ?



$m_q = 0$

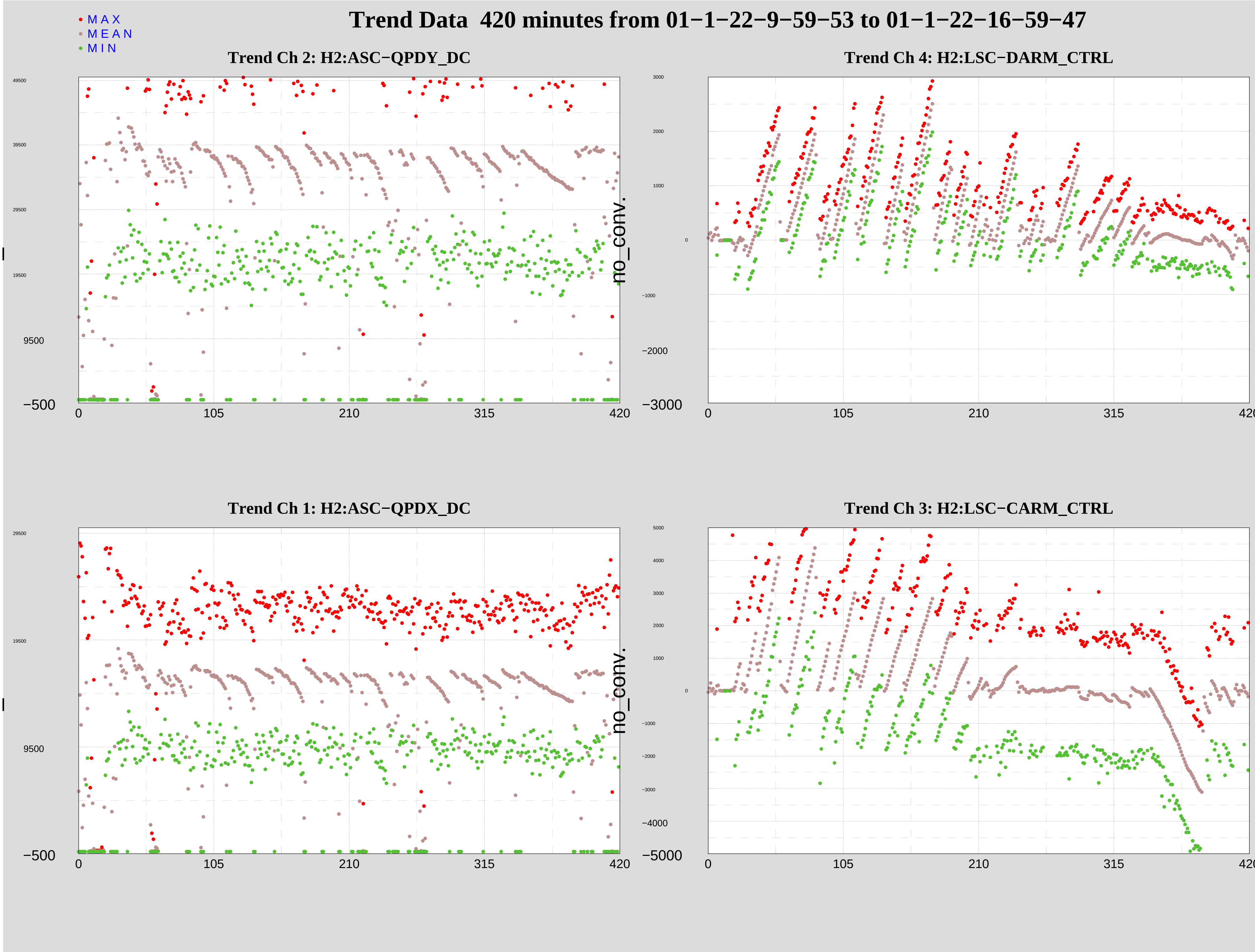
$a = .07$

⇒ F-P ARM MATCH FRACTION = 99.5


60 SECONDS
YARM TRANSMITTED
ACQUISITION
XARM TRANSMITTED
PEAK RECYCLING GAIN ≳ 12
SB POWER
AS_DC
REFLECTED INTENSITY
BS PITCH

Tidal Limit

- Earth tides stretch the interferometer arms
  - Common mode effect to be cancelled by feedback to laser frequency
  - Differential effect to be cancelled by fine-actuation system
  - Neither yet implemented
- The only tidal compensation is currently the local control system
  - limited range
  - sets a natural limit of 10-40 min on lock stretches
  - locking is robust within those periods



Trend Data 420 minutes from 01−1−22−9−59−53 to 01−1−22−16−59−47
MAX
MEAN
MIN
Trend Ch 2: H2:ASC−QPDY_DC
Trend Ch 4: H2:LSC−DARM_CTRL
Trend Ch 1: H2:ASC−QPDX_DC
Trend Ch 3: H2:LSC−CARM_CTRL
no_conv.
49500
39500
29500
19500
9500
−500
3000
2000
1000
0
−1000
−2000
−3000
5000
4000
−4000
−5000
0
105
210
315
420

Installation/Commissioning Overview

- Hanford 2k
  - "Installation" more or less complete: vacuum, seismic, laser, in-vacuum hardware (mode cleaner, core optics, baffles, beamdumps etc), external optics, some LSC and ASC electronics
  - advanced commissioning: stable if noisy locks of the whole IFO!
- Livingston (4k)
  - Substantial progress: vacuum, seismic, laser, all in-vacuum hardware, lots of other stuff
  - Commissioning proceeding apace: 10 s locks of a 4 km cavity
- Hanford 4k
  - Installation held up to allow inclusion of redesigned OSEM
  - In-vacuum hardware being installed.

Data Runs

- 11/00: E2 engineering run
  - Hanford 2km IFO in single arm mode
  - Practice at round-the-clock operation
  - Wide variety of characterization tasks
- 3/01: E3 engineering run
  - Hanford 2 km, full IFO with recycling
  - Livingston 4 km, probably one arm
- Later in 2001
  - First proper coincidence runs
- 2002, 2003+
  - LIGO I Science Run, LIGO I Data Run