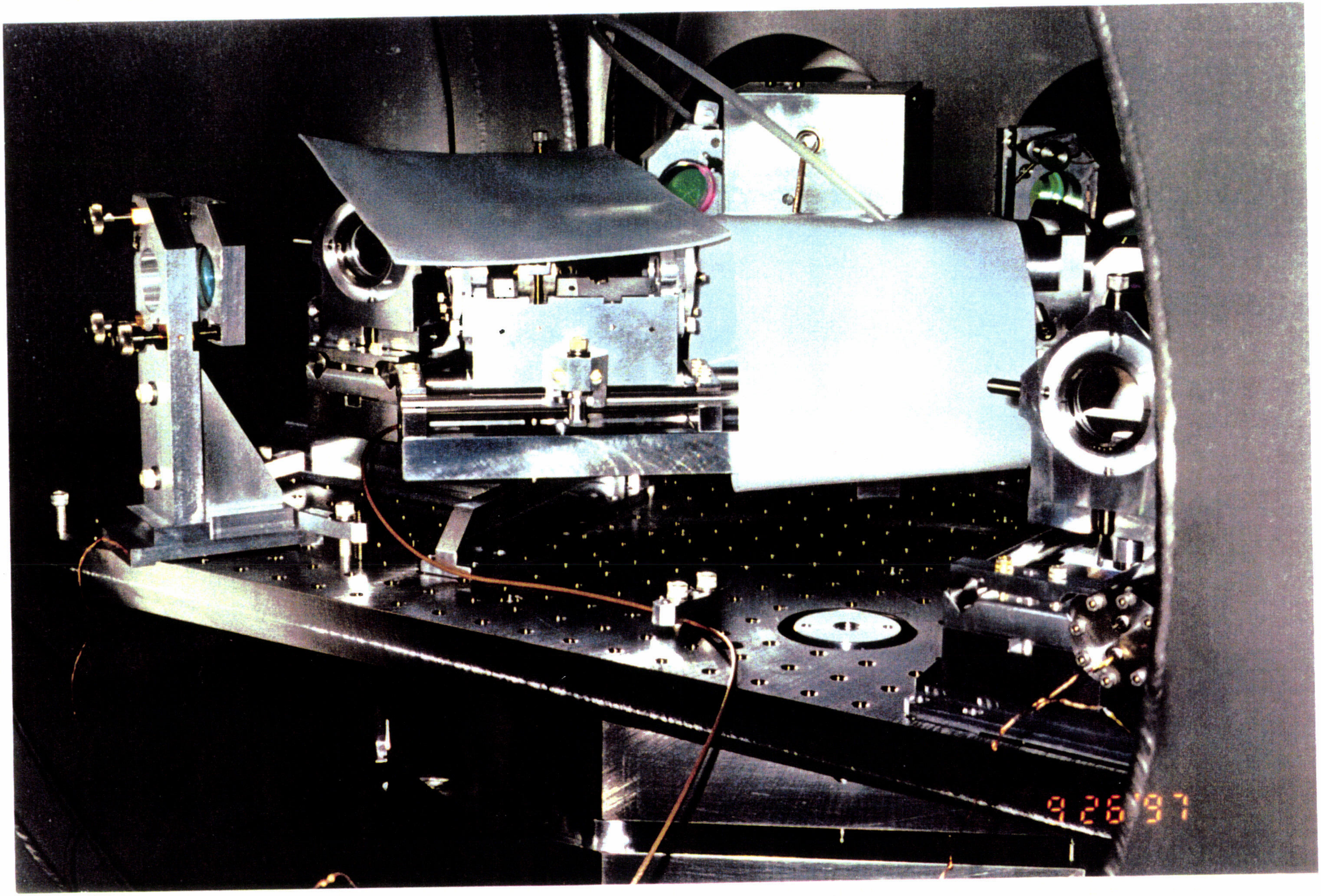
40 Meter Status and Plans

- **Topics Covered:**
  - 40 Meter Status
  - Operating Environment
  - Results and Lessons Learned
  - Future Plans and Schedule
  - The Role of the 40 M within LIGO

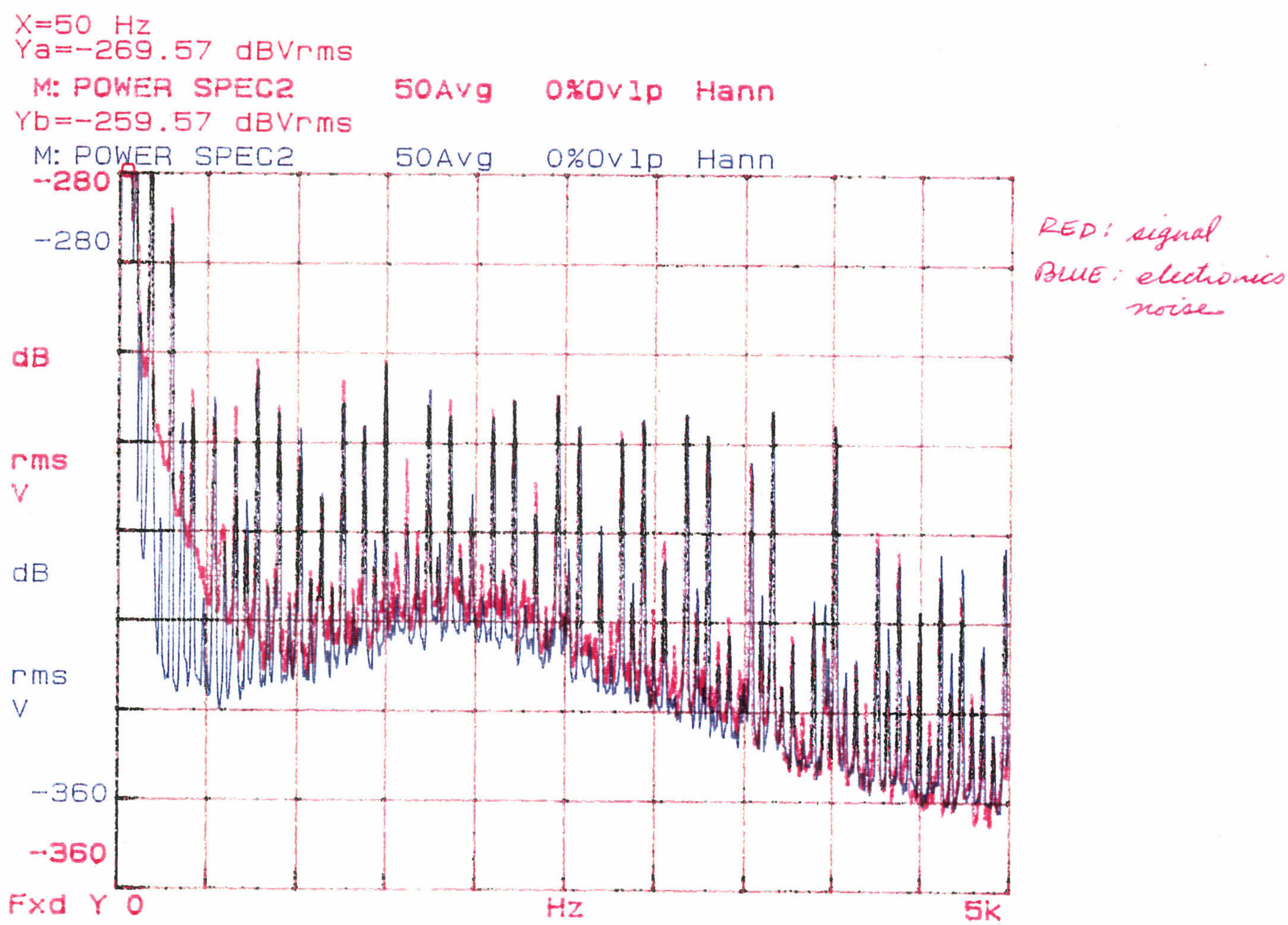
Current status of the 40 m - or "How we spent our summer vacation"

- Lots of hardware failures:
  - **Laser tubes**
    - 3 replacement tubes!
    - Sagging cathode failure on original tube
    - glass-to-metal seal failure on first two replacement tubes
    - 7 weeks lost to laser repair
  - **Electronics failures:**
    - faulty current controller board in the laser power supply
    - Pockels cell HV supply
    - VME power supply
    - phase shifter NIM module
    - east vertex suspension control electronics.
  - Pockels cell degradation

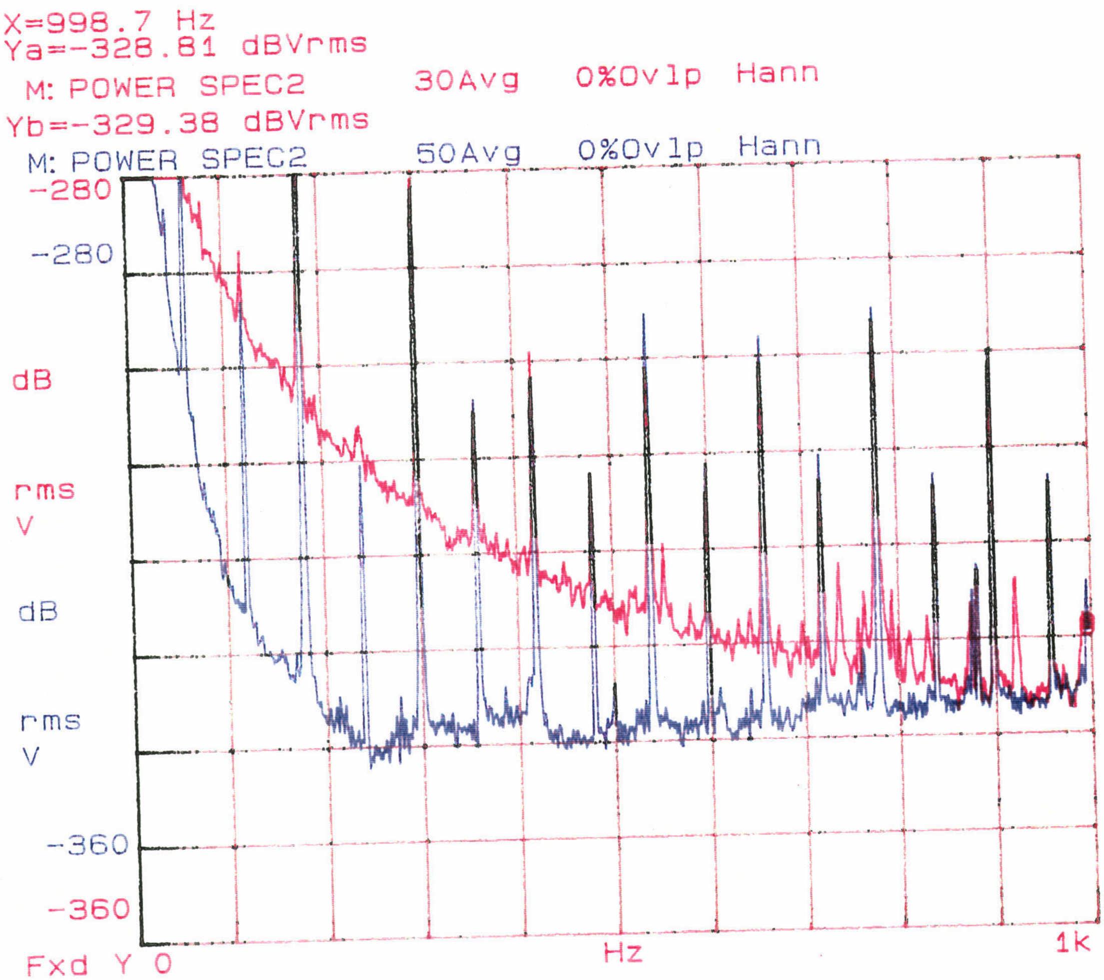

9 26 '97

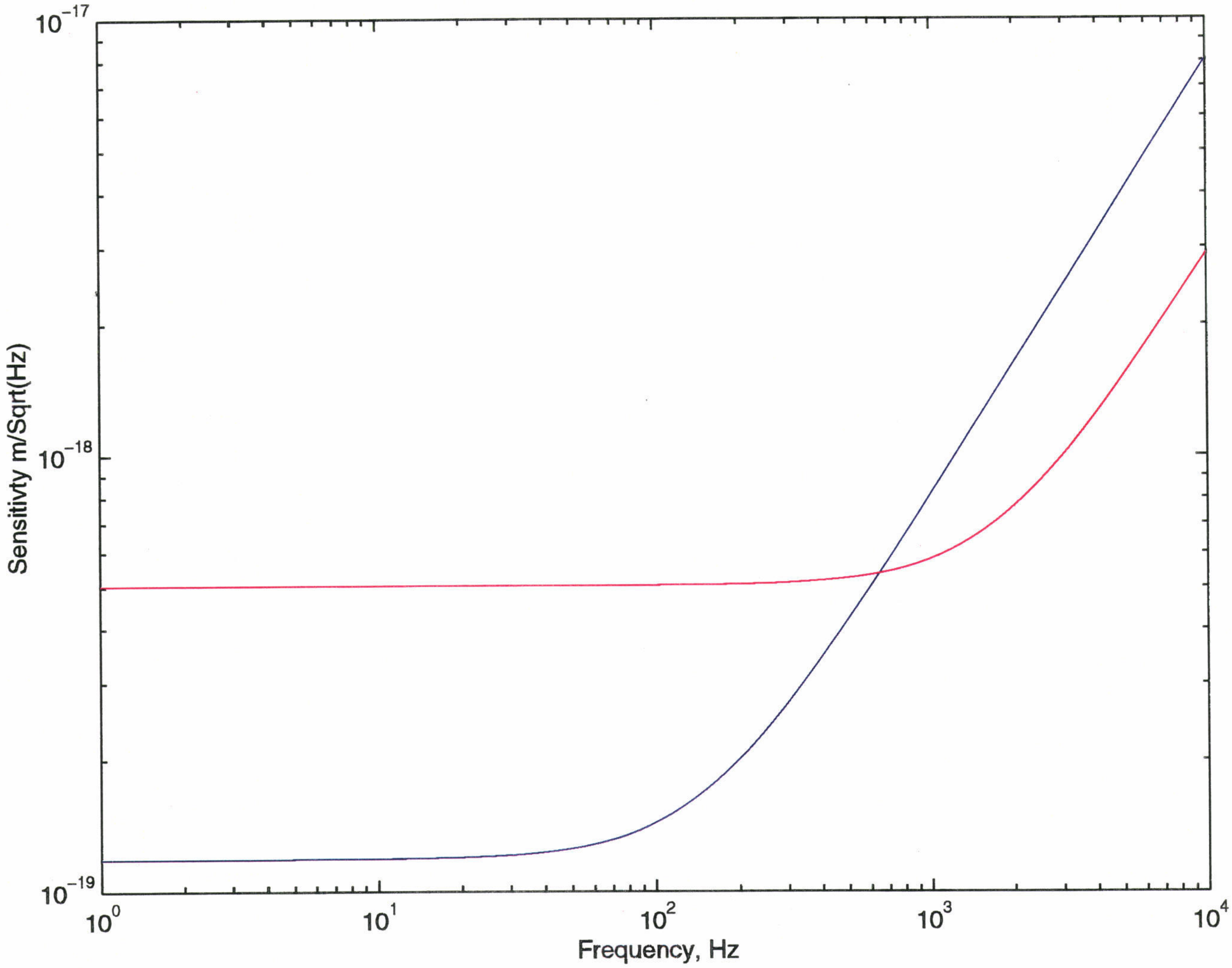
Accomplishments

- Ar+ laser back in operation Aug 15.
- Achieved stable locked status by September 3.
- 10 hours of data recorded
- Power spectrum measured

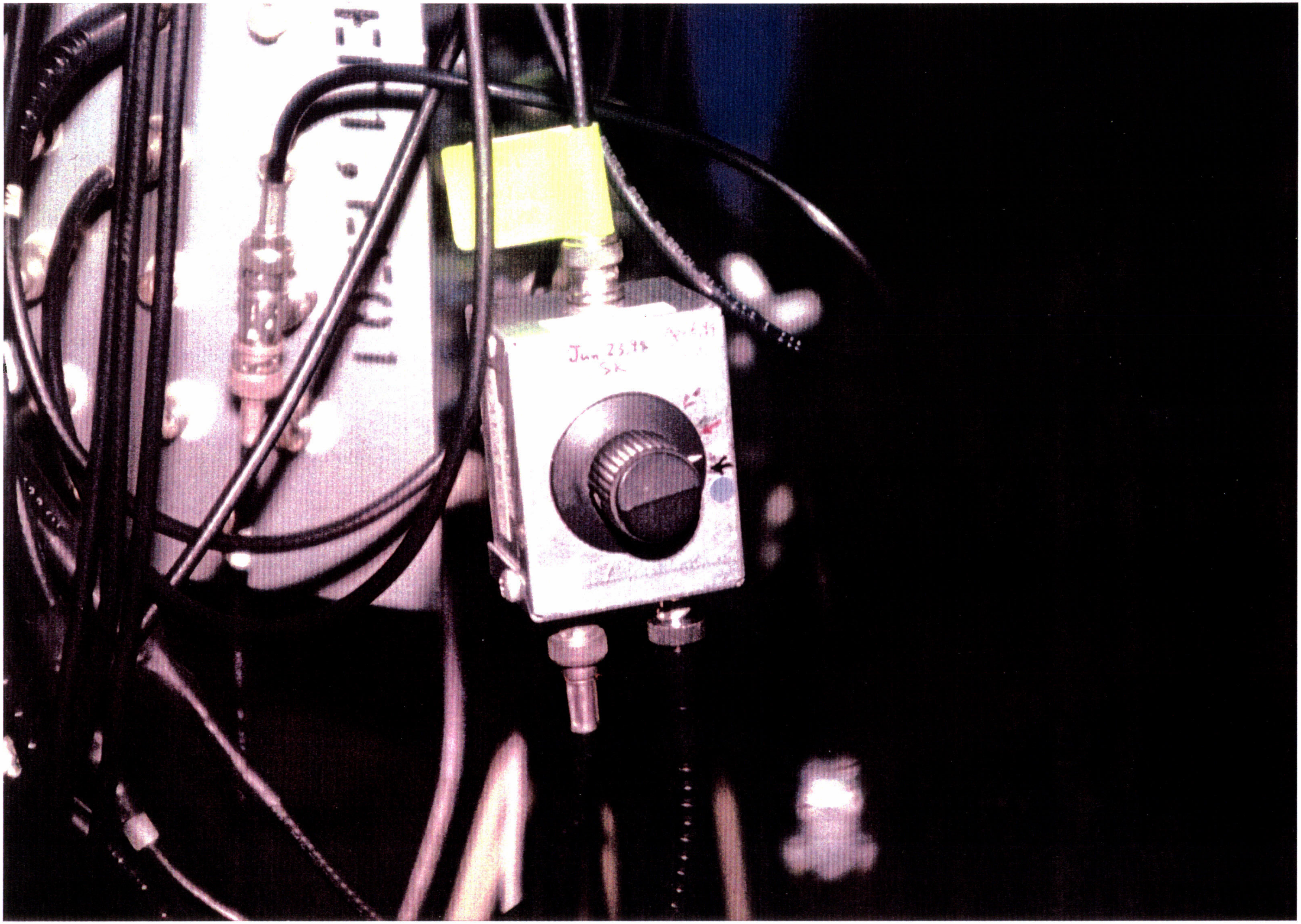


X=50 Hz
Ya=-269.57 dBVrms
M: POWER SPEC2 50Avg 0%Ovlp Hann
Yb=-259.57 dBVrms
M: POWER SPEC2 50Avg 0%Ovlp Hann
-280
-280
dB
rms
V
dB
rms
V
-360
-360
Fxd Y 0
Hz
5K
RED: signal
BLUE: electronics noise


X=998.7 Hz
Ya=-328.81 dBVrms
M: POWER SPEC2 30Avg 0%Ovlp Hann
Yb=-329.38 dBVrms
M: POWER SPEC2 50Avg 0%Ovlp Hann
-280
-280
dB
rms
V
dB
rms
V
-360
-360
Fxd Y 0
Hz
1k



from Jennifer Logan


Jun 25.98
SK

40 M Operating Environment

- How LIGO- like is the 40 m?
  - Similar items:
    - BS suspension
    - RM suspension
  - Non-similar
    - SE, EE suspension

    SV
  - Somewhere in between:
    - EV (new suspension, NIM controller)
    - RF source
    - PSL

40 M is a table top experiment environment - not a *"production"* environment

- It *could be* a production platform, but this would require commissioning a 3rd observatory simultaneously with Hanford and Livingston.
- Because of LIGO schedule demands, future 40 M experience is not a major factor in *most* LIGO system designs
- There is the opportunity to incorporate some lessons learned into LIGO

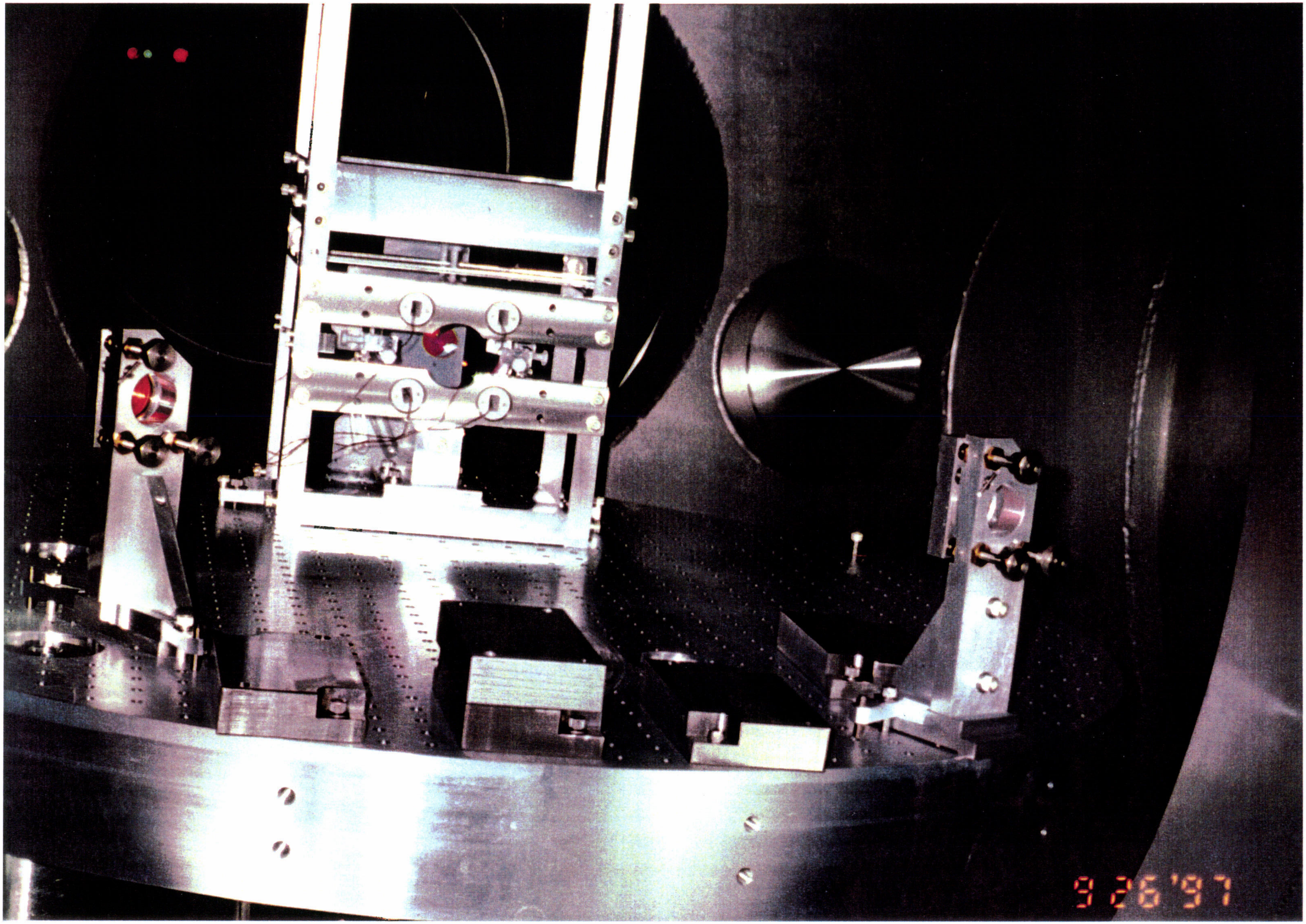
Schedule Considerations

- Projected LIGO FDR Dates:

ASC	2/98
LSC	3/98
DAQ	7/98
PSL	11/98

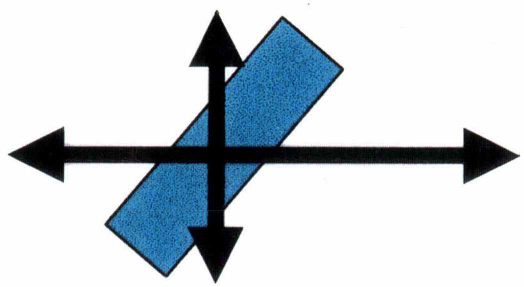
Lessons Learned

- OSEMs
- Suspension alignment
- Suspension standoffs
- RF layout sensitivity
- Software interfaces
- Reliability history
- Opportunities to develop realtime software diagnostics based on experience

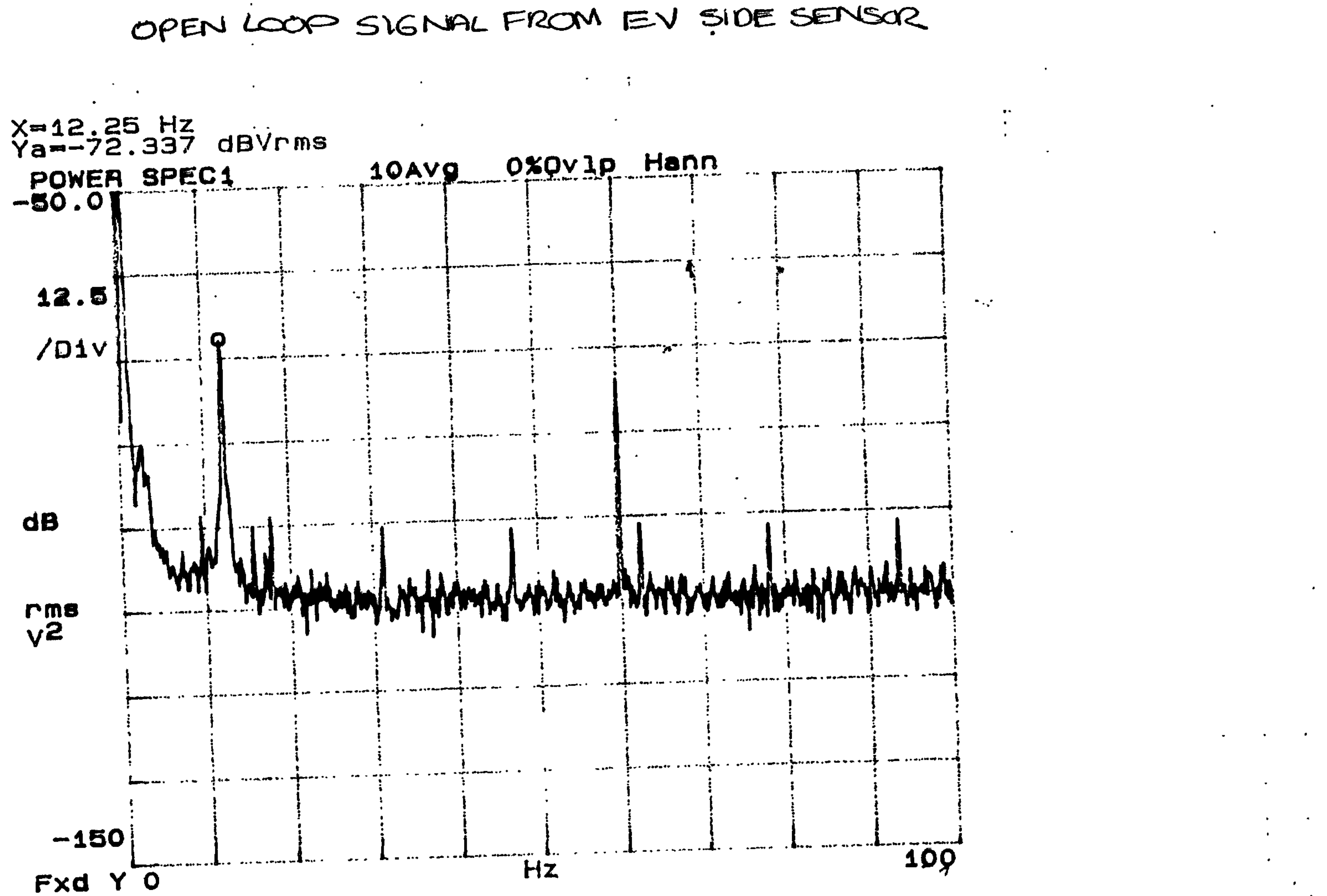

9 26 '97

OSEM Alignment

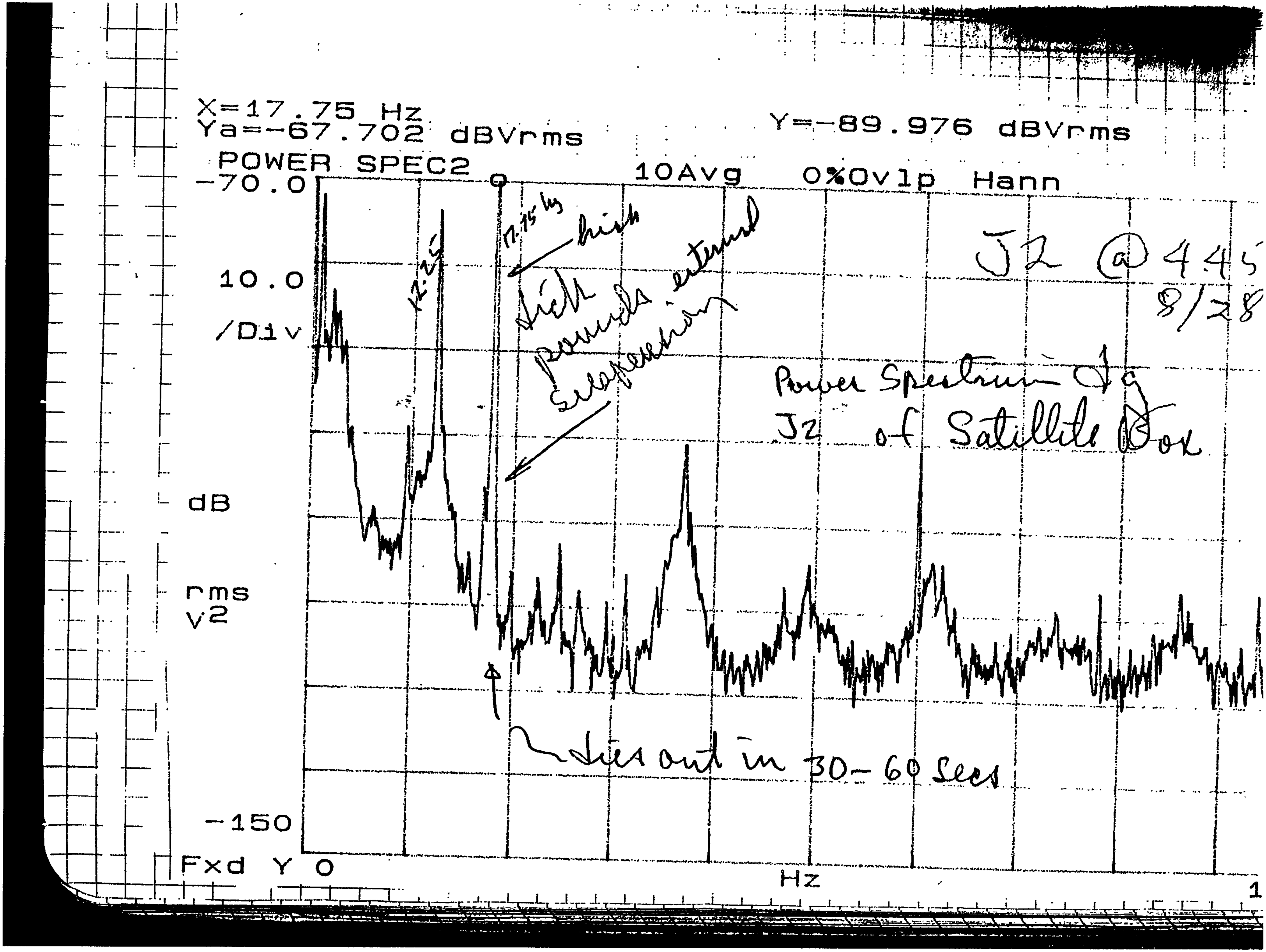
- Jennifer Logan's observation that misaligned OSEM slot couples vertical and horizontal oscillations.



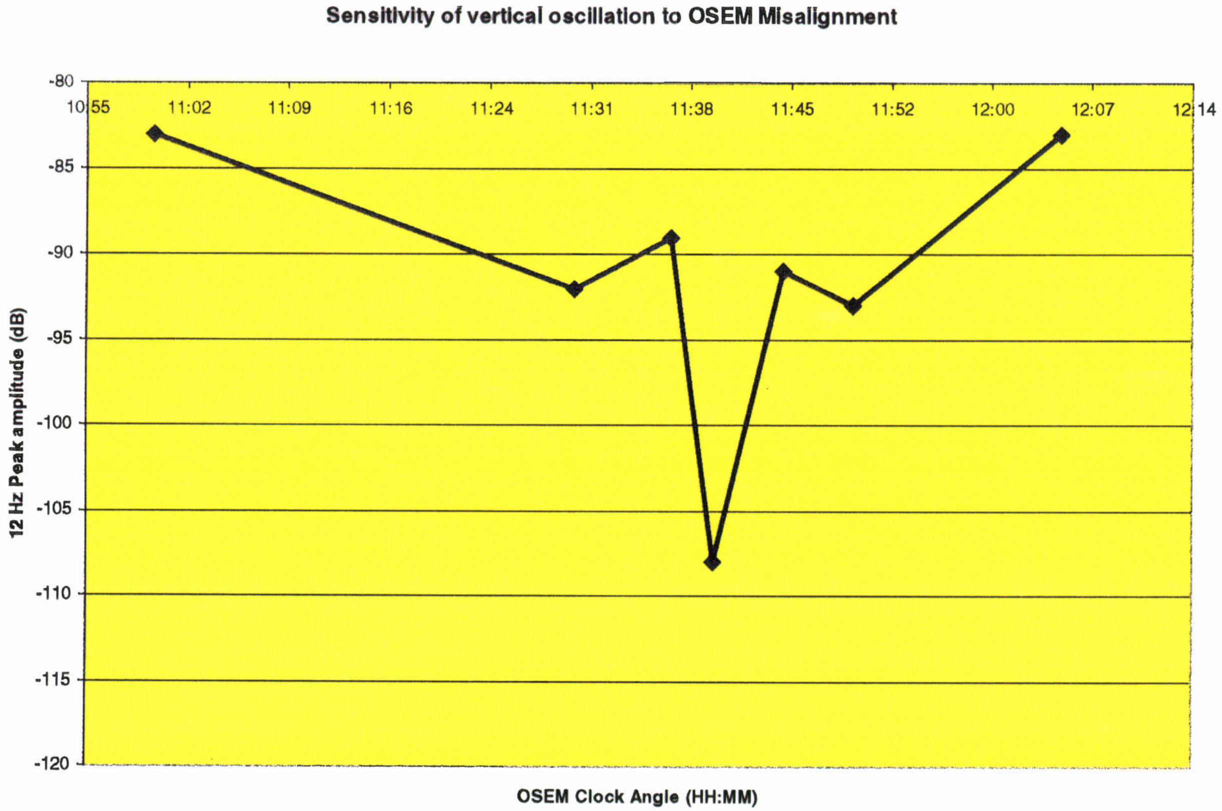
- OSEM orientation is very sensitive to angular orientation of sensor slot

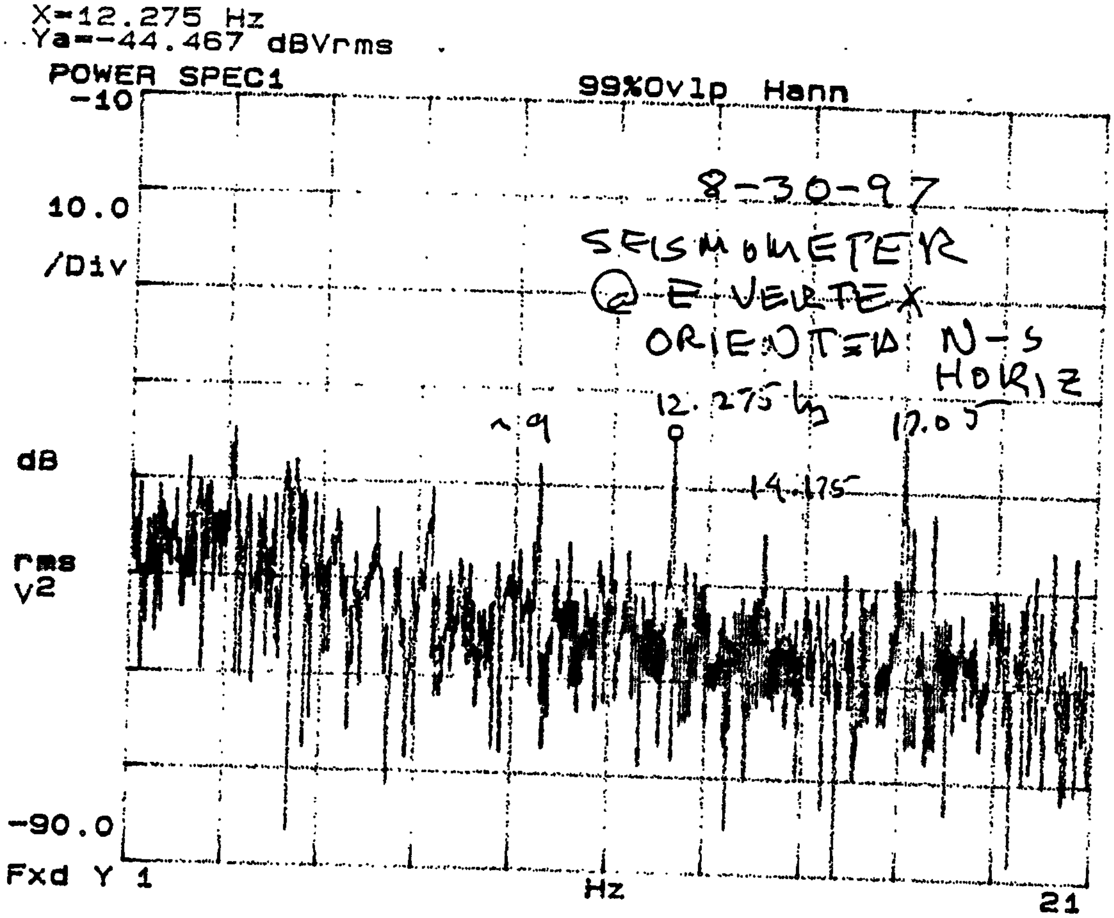


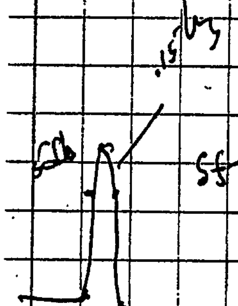
08/27/97
14:45
JEL, NM, BW
OPEN LOOP SIGNAL FROM EV SIDE SENSOR
X=12.25 Hz
Ya=-72.337 dBVrms
POWER SPEC1
10Avg
0%Ovlp
Hann
-50.0
12.5
/Div
dB
rms
V2
-150
Fxd Y 0
Hz
100


X=17.75 Hz
Ya=-67.702 dBVrms
Y=-89.976 dBVrms
POWER SPEC2
10Avg
0%Ovlp
Hann
-70.0
10.0
/Div
dB
rms
V2
-150
Fxd Y 0
Hz
17.75 hz
high
J2 @ 4:45
8/28
Power Spectrum of
J2 of Satellite Box
dies out in 30-60 secs

OSEM Angular Sensitivity







$\frac{1}{Q} \sim \frac{\Delta f}{f} \lesssim \frac{.3}{12}$

Q ≳ 40

GROUND VIBRATION from SEISMOMETER

following hypothesis:

12 Hz is due to vert EV mass — $f = 12.275$

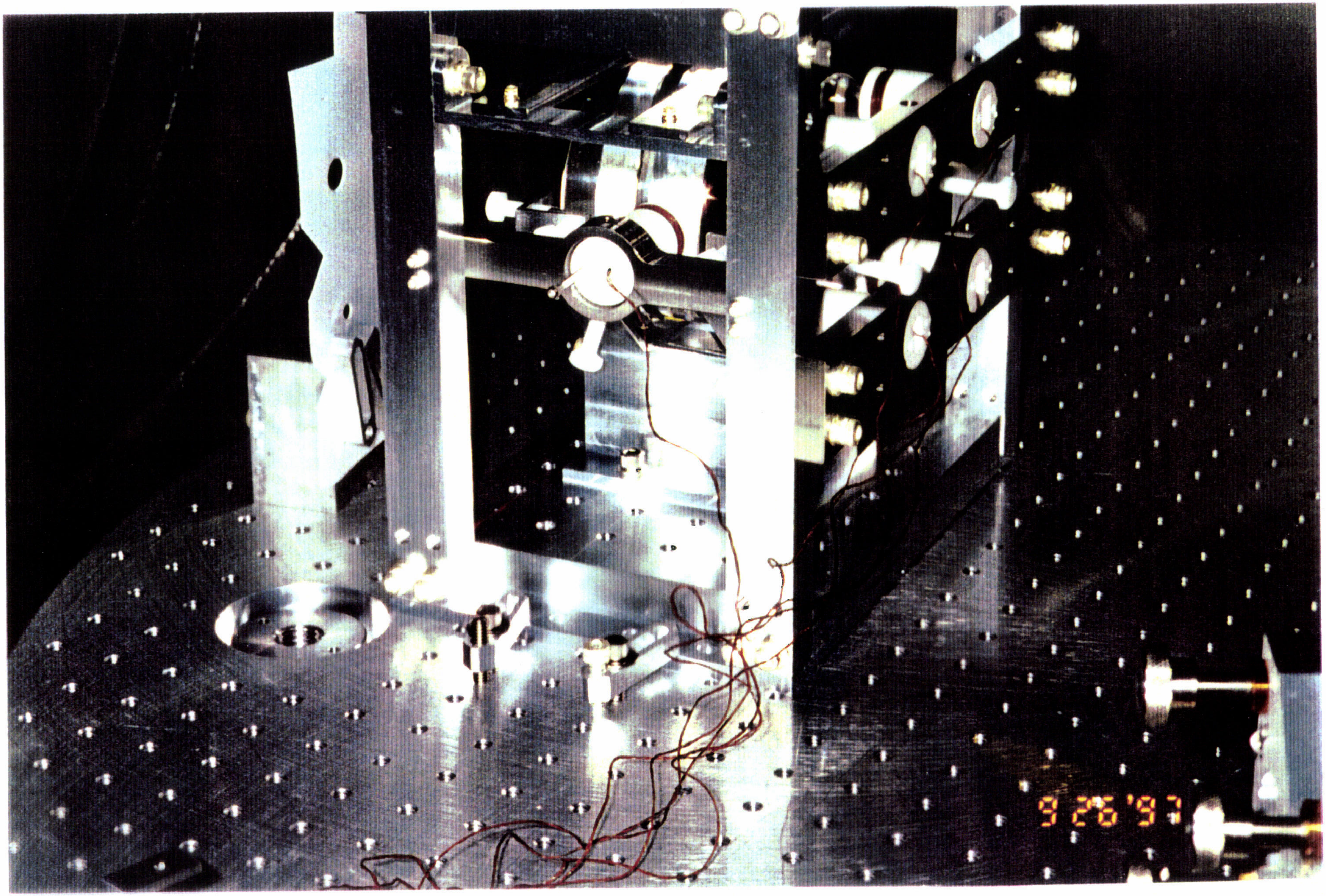
and EV mass is NOT BALANCED.

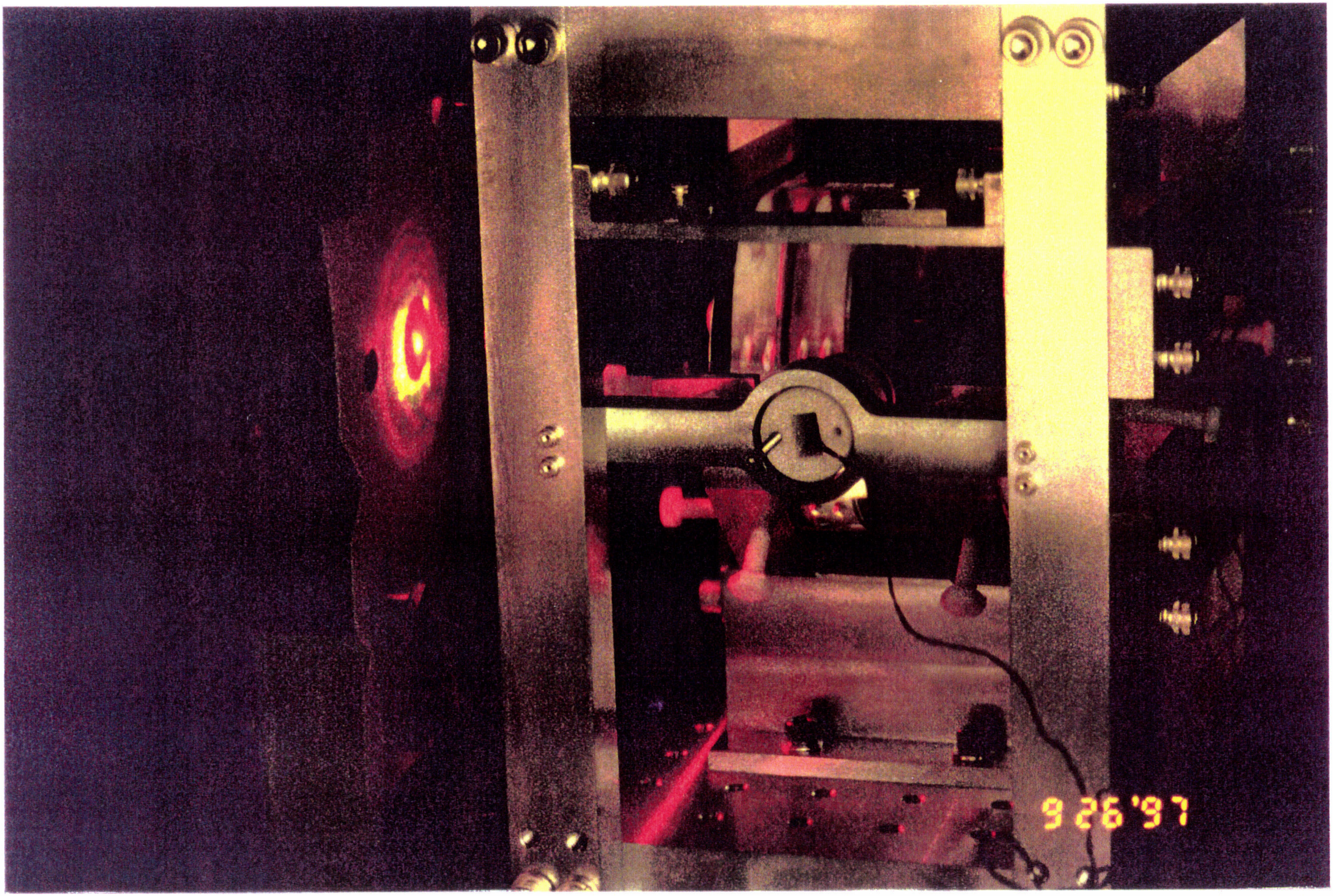
and thus EV servo system 'sees' this.

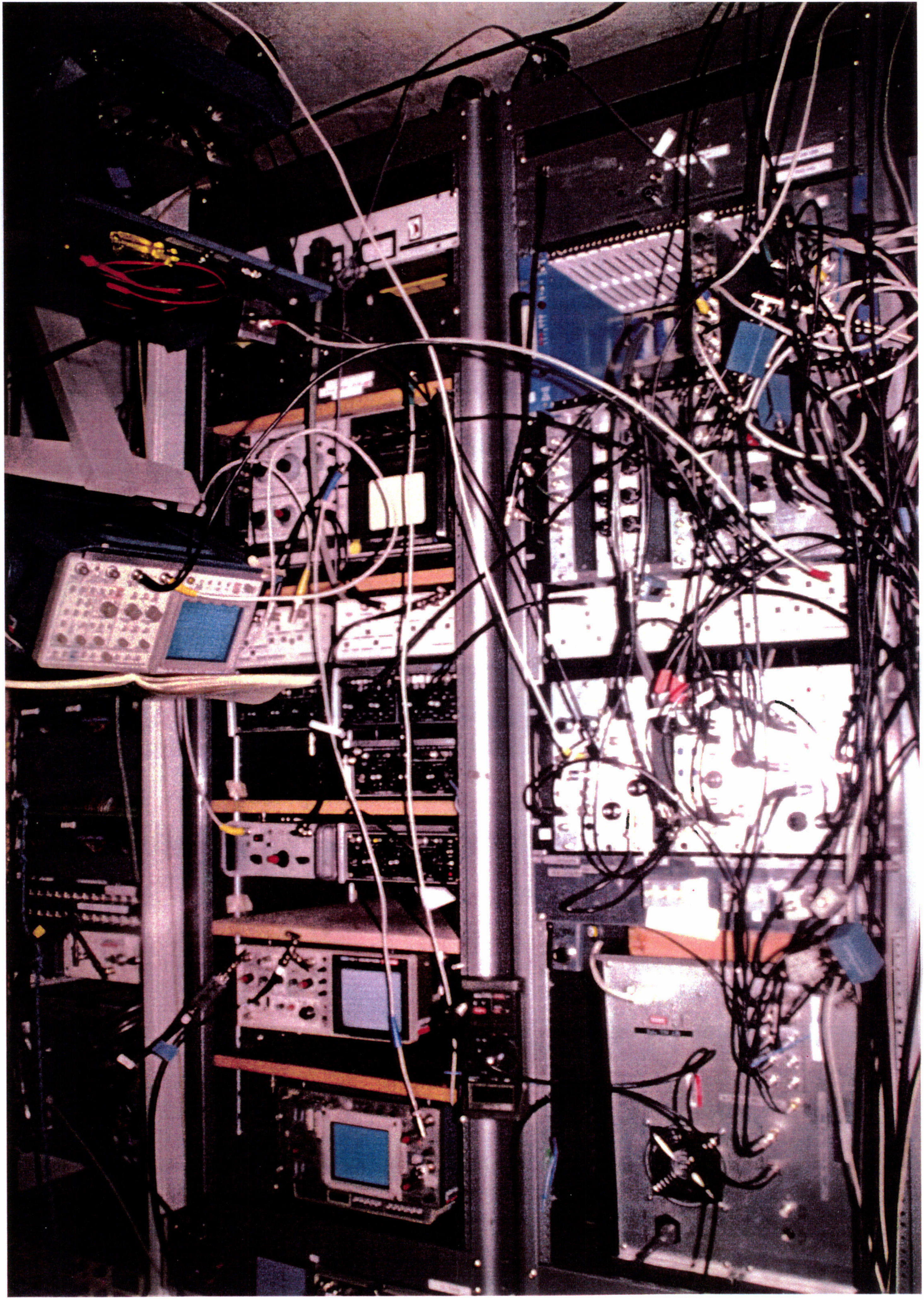
NEXT: EW + then maybe verticle.

Alignment Tools

- show alignment tool

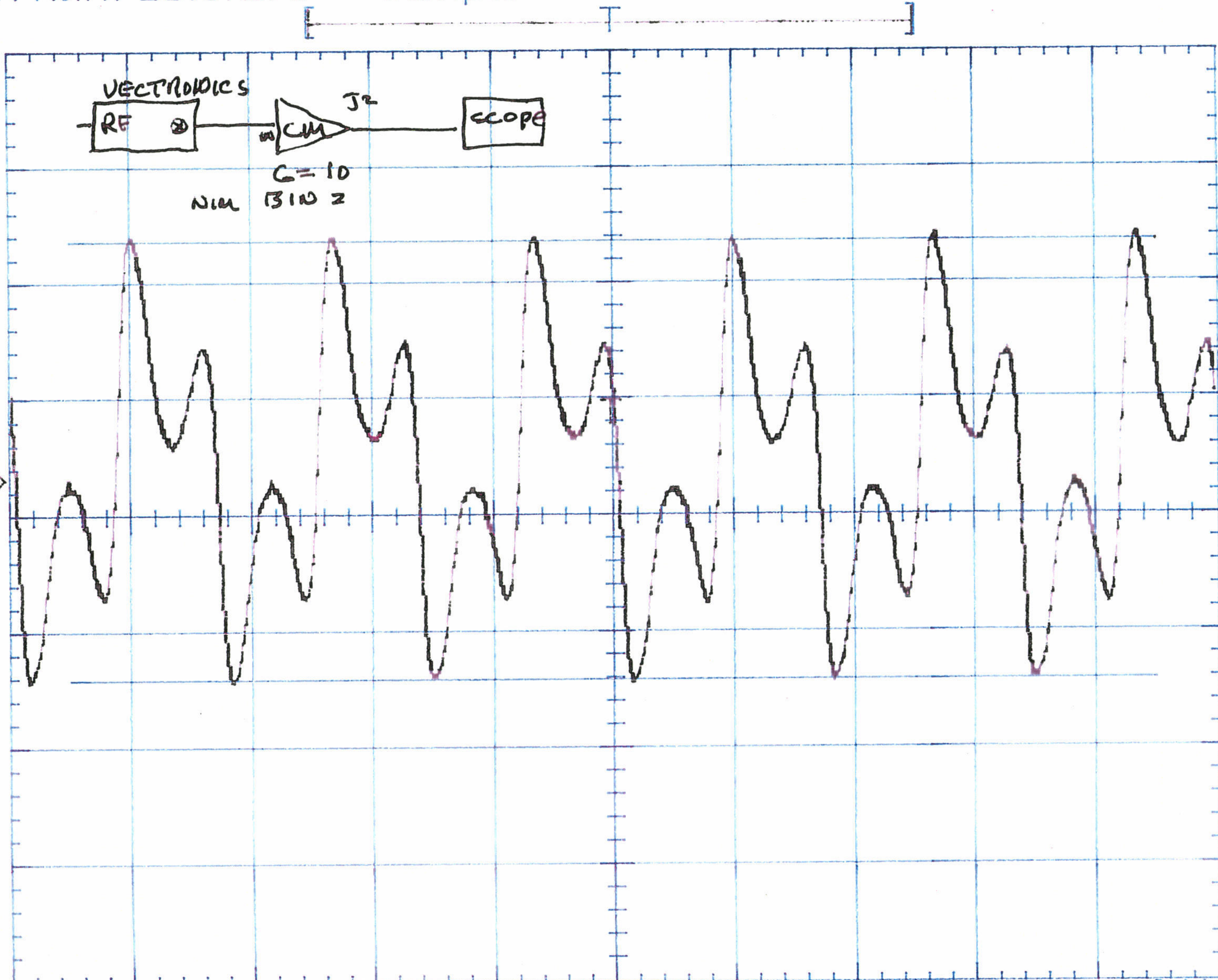

9 26 '97


9 26 '97



From Dick Gustafson

Tek Run: 25.0kS/s Sample



Δ: 76.0mV
@: -35.2mV

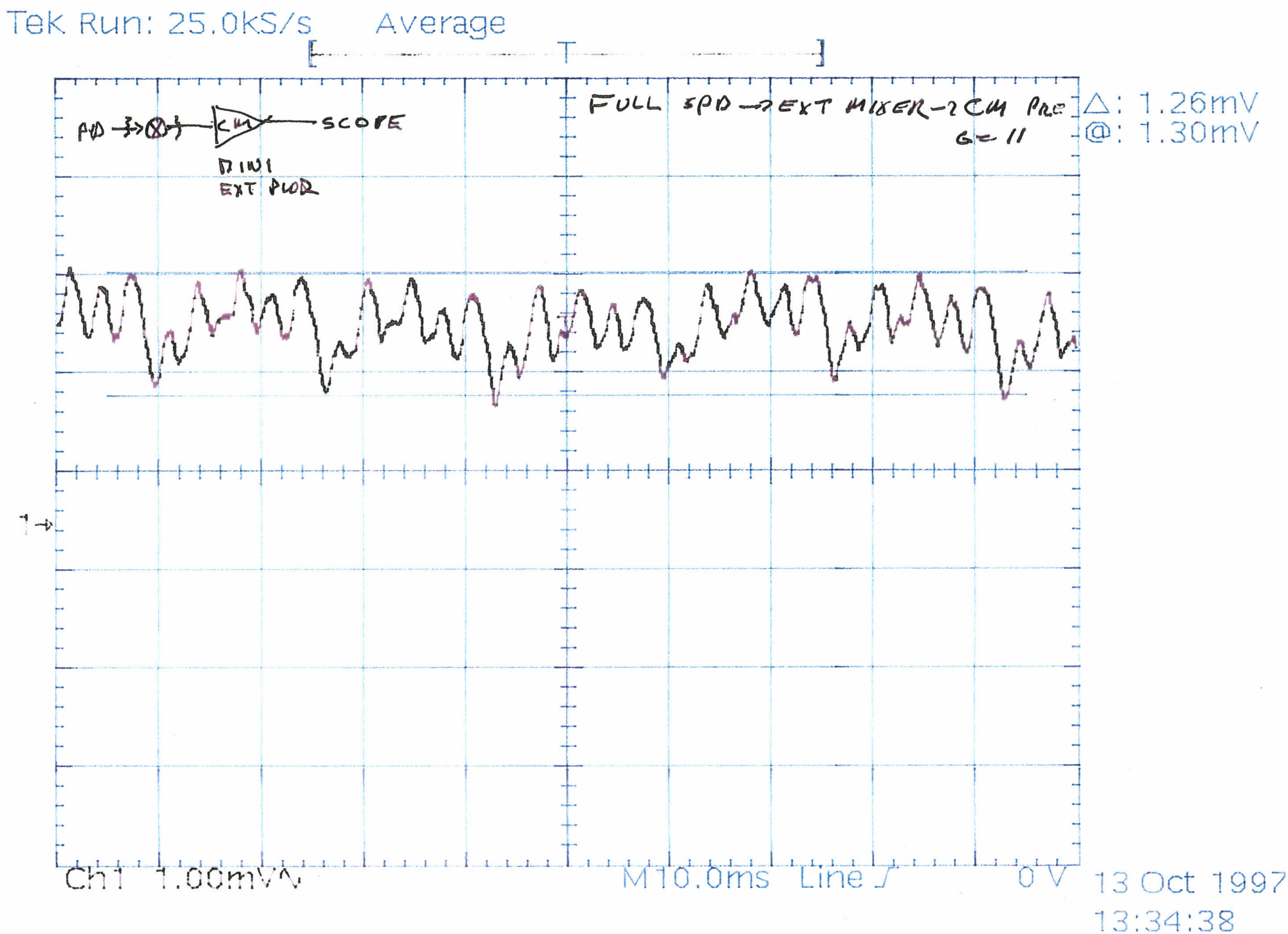
COMMON PREAMP
G=10 BIN 2
J2 POWERED

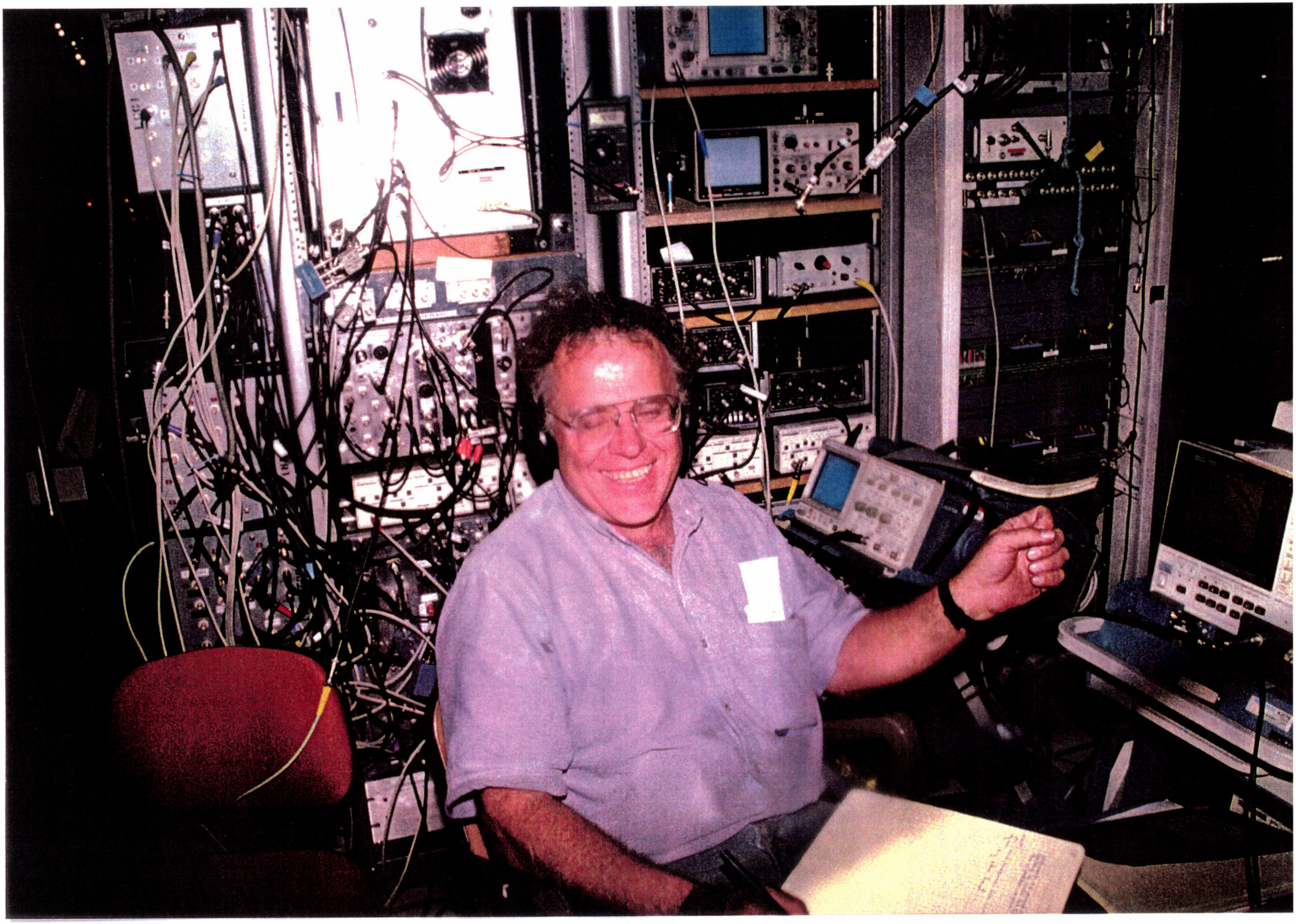
CONNECTED TO
RF SOURCE 2
LONG CABLE
THRO BACK

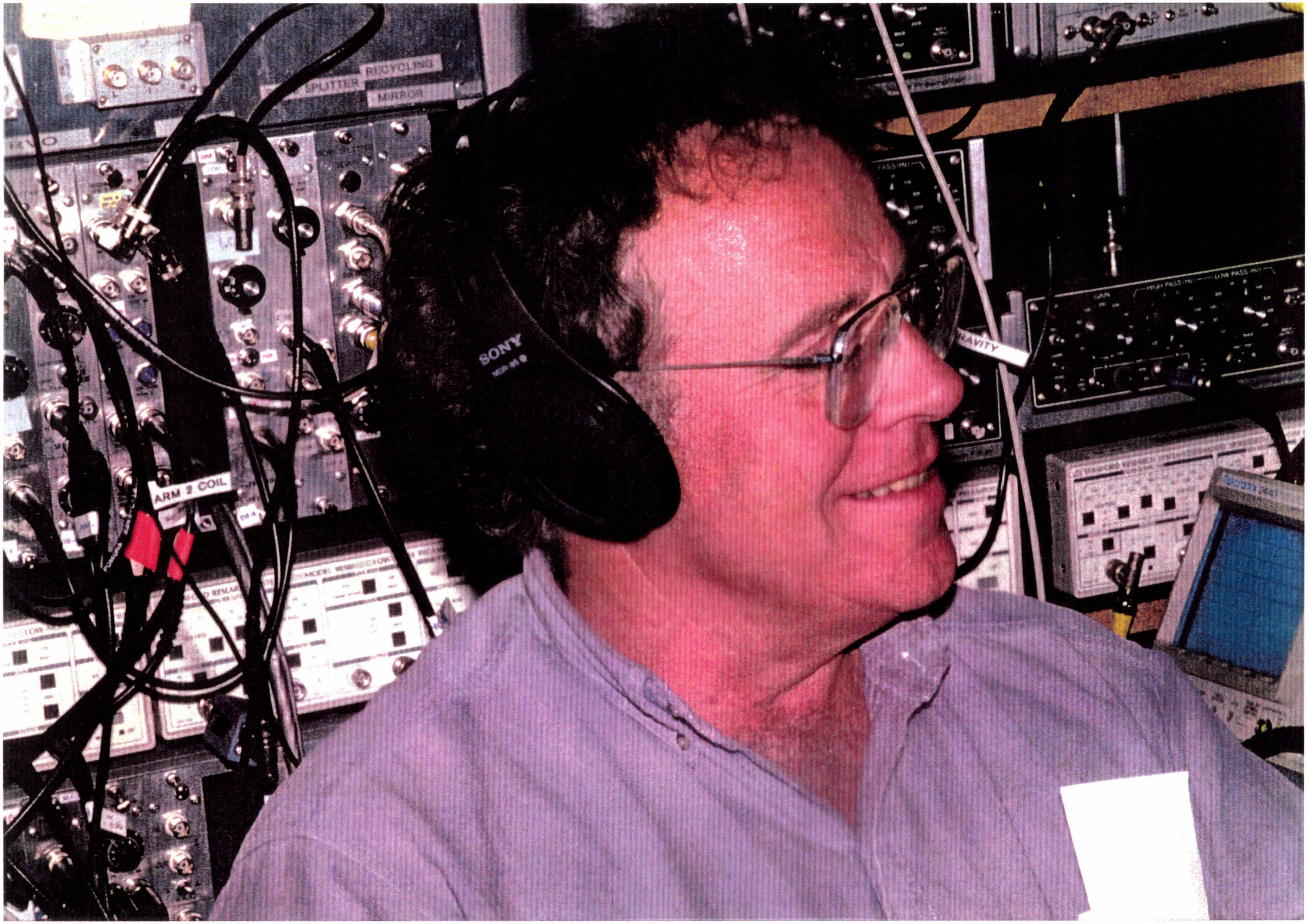
Ch1 20.0mV∿ M10.0ms Line ∫ 0 V

13 Oct 1997
11:43:55

From Dick Gustafson






RECYCLING
MIRROR
SPLITTER
ARM 2 COIL
SONY

Reliability

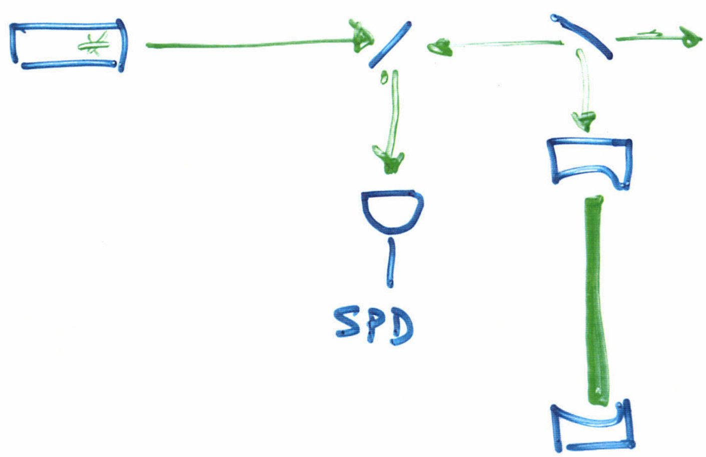
- We need to teach the machine to do what Dick's ears can do
- Documentation
  - Trouble shooting in the 40m is an indicator of the level of infrastructure needed in the field. What kind of documentation is needed to sustain operation in the field
  - Layout drawings, theory of operation etc. in addition to schematics and procedures

Software Modelling

- Opportunity to validate some aspects of LIGO end-to-end model as it develops within the 40m environment.
- Malik Rakhmanm, Hiro Yamamoto, Matt Evans, Guoan Hu are in the initial phase of this effort.
- Potentially critical tool for LIGO commissioning

Modelling Effort
(Malik, Matt, Hiro, Guan)

Opportunity to validate LIGO end-to-end model as it is being developed



- Use model to identify structures in SPD time trace
- From observed structure, determine:
  - > South arm cavity length
  - > Relative velocity of end test mass
  - > See how fine structure observed compares to model

L_m = modulation wavelength
= distance at which phase of sideband leads or lags carrier by 2π

$$(N-1)\lambda_+ = N\lambda_0 = L_m$$

Phase difference at distance x

$$= 2\pi N + \Delta x\,(k_0 - k_+)$$

up to modulo 2π $= \Delta x\,\Delta k = 2\pi \dfrac{\Delta t}{T}$

Δt = time between carrier & sideband

T = time from carrier to carrier
= time to go $\dfrac{\lambda}{2}$

$$\Delta x = \frac{1}{2} L_m \frac{\Delta t}{T}$$

```
% speed of light (m/s)

c = 299792458;

% modulation parameters

fmod = 32.7e6;
l_mod = c/fmod;

% approximate length

L0 = 38.5;

% beat number

m = floor(2 * L0/l_mod);

% exact length

L = (1/2) * (m + ratio) * l_mod
```

10/8/97

Results:

ratio

0.4072

0.4092

0.4087

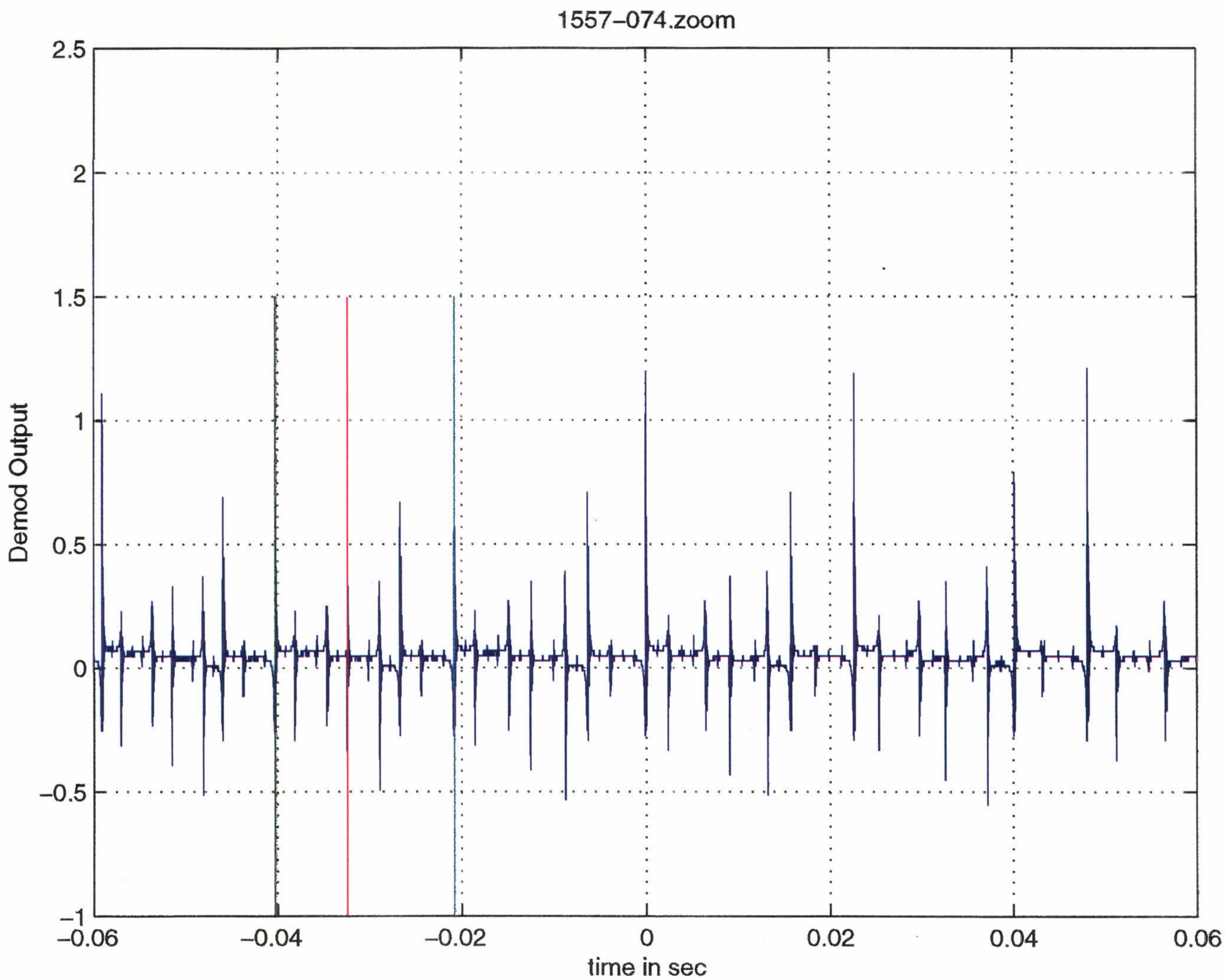
0.4088

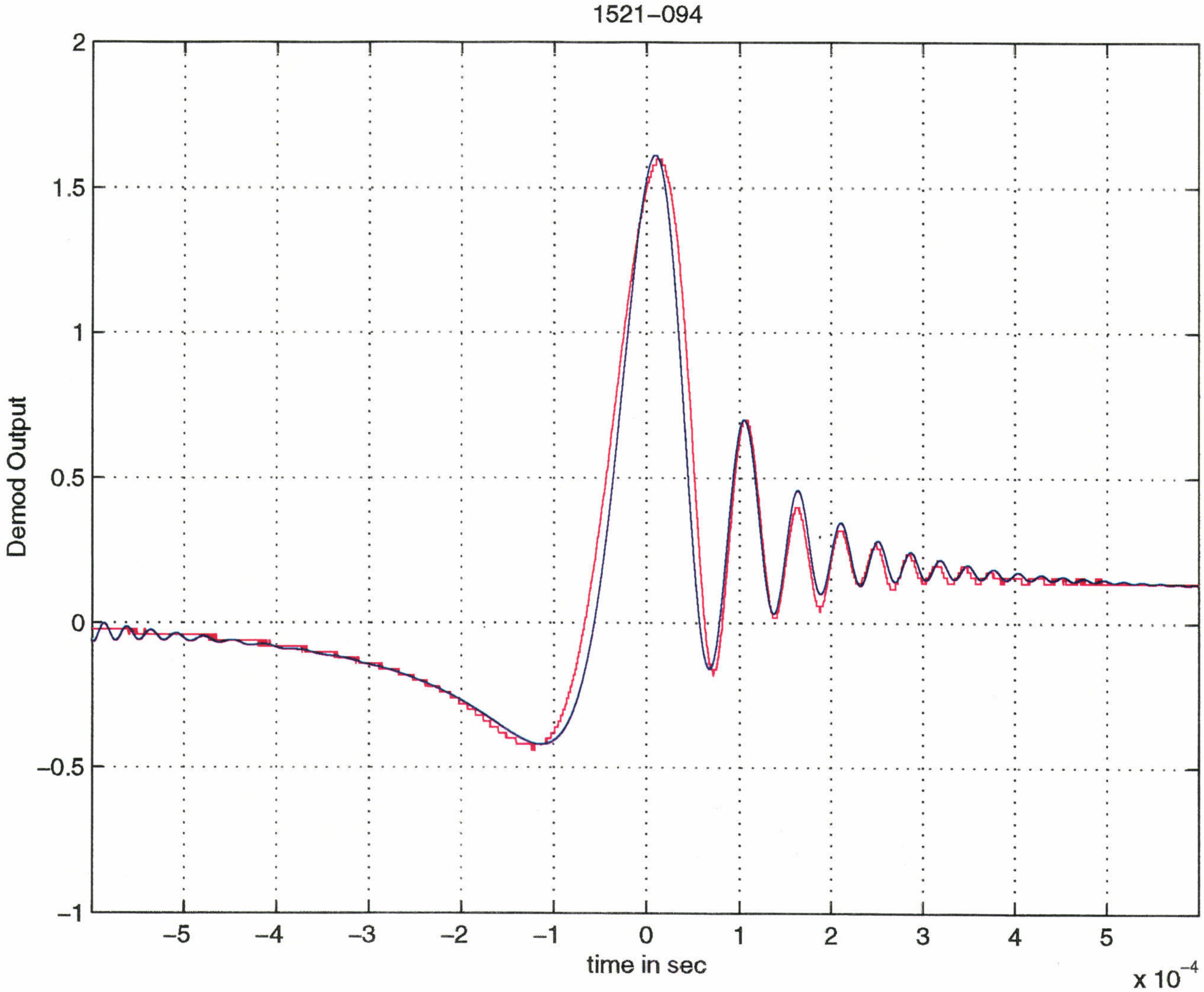
0.4097

ratio = 0.4087 +- 0.0004

<L> = 38.5453 +- 0.0036 m

From Malik Rakhman





1521−094
Demod Output
2
1.5
1
0.5
0
−0.5
−1
−5
−4
−3
−2
−1
0
1
2
3
4
5
time in sec
x 10^−4

ID	Task Name	Duration
1	**1.0 Non-recycled IFO**	9d
8		
9	**2.0 Recycle Preparation**	15d
16		
17	**3.0 Recycling**	211d
18	***3.01 Realign IFO***	1d
19	***3.1 Lock Michelson with new servo - misalign RM***	6d
24	***3.2 Align RM, misalign vertex mass***	10d
28	***3.3 Lock PR Michelson***	15d
32	***3.4 PRM + 1 arm***	21d
40	***3.5 PRM + 2 arms - full IFO***	30d
48	***3.6 Recycling Shakedown***	130d
50		
51	**4.0 Wavefront sensing**	122d
52	***4.1 Preparation during vent***	4d
55	***4.2 Activity linked to green light in recycled configuration***	15d
61	***4.3 WFS Signal Tune up***	22d
66		
67	**5.0 Data taking**	8d
68	5.1 Evening data taking	8d

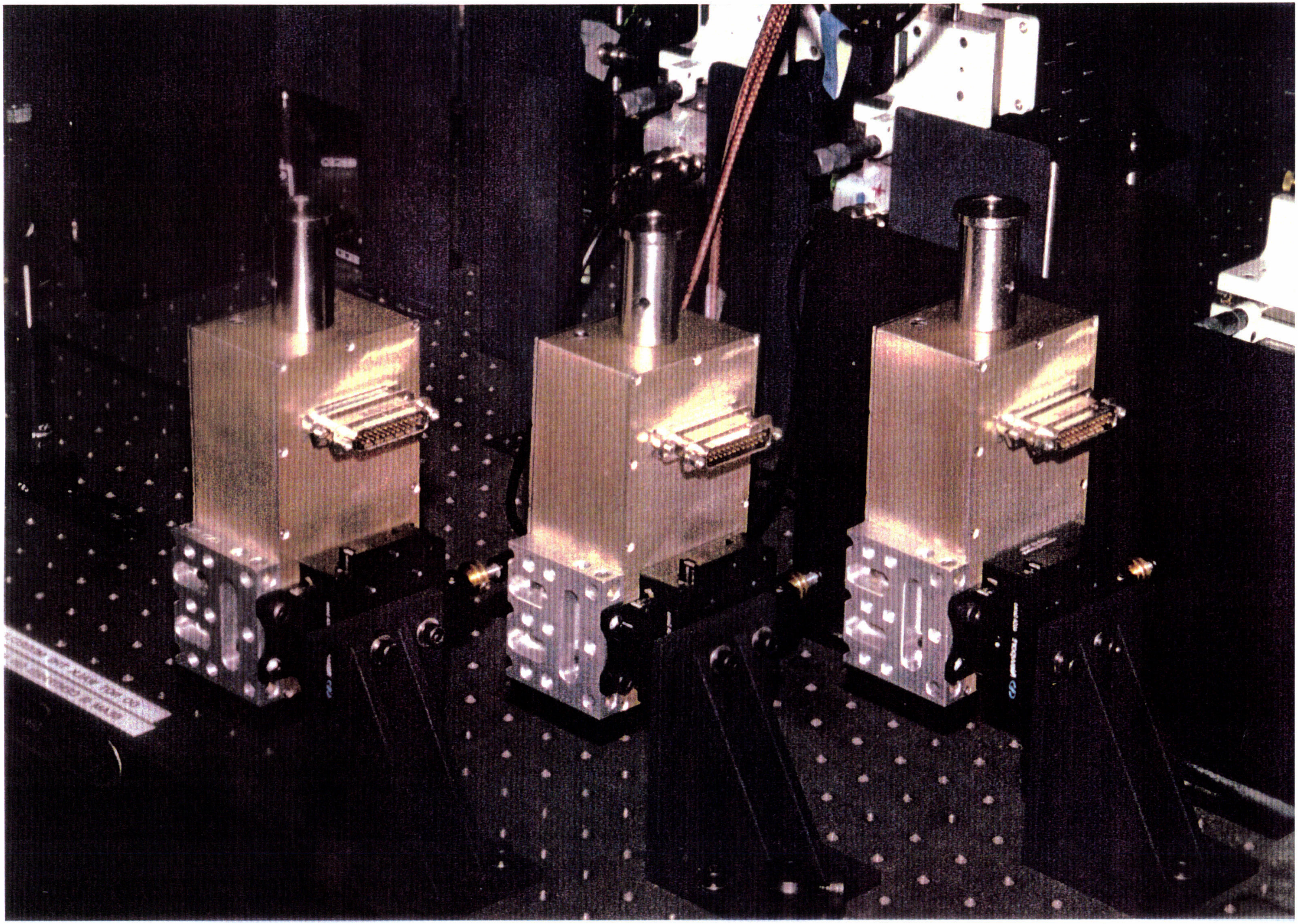
Project: 40 Meter 1 year schedule
Date: Sun 10/12/97

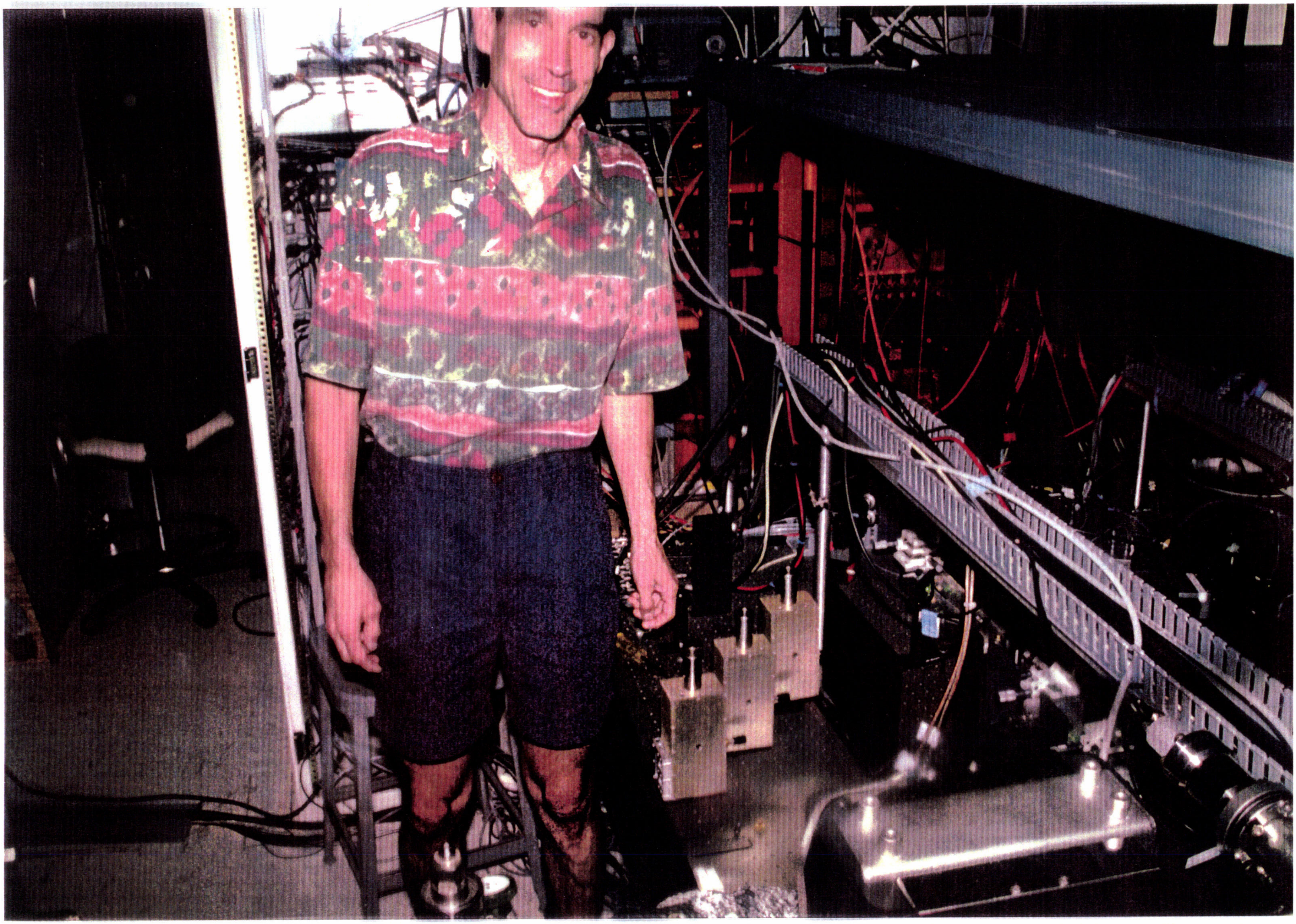
Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

40m Wave Front Sensing (WFS) - STATUS

(Bill Kells)

- System design finished (4/97)
  - MIT/FMI Electronics and WFS sensor heads
  - Detailed analysis for 40m configuration and parameters
  - 40m implementation engineered; hardware all ordered.
  - Decision to use existent MC locking RF for needed NR side band





WFS Status (ctd)

- Optics and WFS heads installation complete (9/97)
    - One Asymmetric port WFS (arm cavity differential alignment)
    - Three symmetric port WFS (one duplexed)
- Loop filter and control electronics (~80% complete 8/97)
    - Loop filter shapes designed.

WFS Status (ctd)

- Orientation controller hardware modifications (partially complete)
- Need VME interface to 40m server
- New rack for loop electronics and system cabling

40 Meter WFS Plan

(Bill Kells)

- Complete installation (~end 10/97)
  - New rack placement (adjacent RM, BS, EV controller rack)
  - Bring VME hardware from CDS.
  - Integrate control of rack electronics with EPICS/monitor.

WFS Plan (ctd)

- Modulation tests (~mid 10/97)
  - Use former (12.33 Mhz) APD as detector
  - Characterize at actual recycling light levels (RC locked)
  - Check WFS head and Guoy telescope alignment with LaserMax diode
  - Use data to set up loop gains

WFS Plan (ctd)

- Open loop alignment signal evaluation
  - Compare to globals and cavity level fluctuations (8/97 data)
  - Tune up system (optimum ϕ_{Guoy} , beam alignment, head tuning)
- Close loops sequentially

Noise studies

- scale to LIGO - useful for LIGO commissioning,
  - provides expected operating parameters.
  - reduces commissioning time.
- Develop diagnostic procedures that can be used to commission LIGO:
  - determine method to inject and read out laser frequency noise
  - similar objectives for intensity, pointing, electrical, shot noise, etc.

Opportunities for data taking

- Operating the 40m is motivated primarily by noise studies.
- If we can obtain a reasonable noise spectrum and "in-lock" duty factor, then limited data taking (~100 hours) for science objectives can be pursued in parallel.

Possible Science Objectives

- Upper limit on local galaxy neutron star binary inspiral rate
  - ~100 hour run (time scale set by Glasgow/Garching data)
  - Theoretical upper limit is about one every billion years +/- two orders of magnitude, so running for 100 hours versus 1000 hours is irrelevant
- Targeted CW search
- Broad-band galactic search

5 August 1996

PHYSICS LETTERS A

ELSEVIER

Physics Letters A 218 (1996) 175–180

Results of the first coincident observations by two laser-interferometric gravitational wave detectors

D. Nicholson [a], C.A. Dickson [a], W.J. Watkins [a], B.F. Schutz [a], J. Shuttleworth [a], G.S. Jones [a], D.I. Robertson [b], N.L. Mackenzie [b], K.A. Strain [b], B.J. Meers [b], G.P. Newton [b], H. Ward [b], C.A. Cantley [b], N.A. Robertson [b], J. Hough [b], K. Danzmann [c], T.M. Niebauer [c], A. Rüdiger [c], R. Schilling [c], L. Schnupp [c], W. Winkler [c]

[a] *Department of Physics and Astronomy, University of Wales College of Cardiff, Cardiff, UK*

[b] *Department of Physics and Astronomy, University of Glasgow, Glasgow, UK*

[c] *Max Planck Institute for Quantum Optics, Garching, Germany*

Received 10 April 1996; accepted for publication 16 May 1996
Communicated by P.R. Holland

Abstract

We report an upper bound on the strain amplitude of gravitational wave bursts in a waveband from around 800 Hz to 1.25 kHz. In an effective coincident observing period of 62 hours, the prototype laser interferometric gravitational wave detectors of the University of Glasgow and Max Planck Institute for Quantum Optics, have set a limit of 4.9×10^{-16}, averaging over wave polarizations and incident directions. This is roughly a factor of 2 worse than the theoretical best limit that the detectors could have set, the excess being due to unmodelled non-Gaussian noise. The experiment has demonstrated the viability of the kind of observations planned for the large-scale interferometers that should be on-line in a few years time.

1. Introduction

Gravitational radiation is expected from a wide range of astrophysical sources such as stellar collapses, mergers of neutron star and black hole binaries, pulsars, and from the very early universe. In order to have an appreciable chance of detecting this radiation, theoretical calculations indicate that gravitational wave detectors should attain an effective strain sensitivity h better that about 10^{-21} over a bandwidth from a few hundred Hz to about 1 kHz [1,2]. It is anticipated that this target will be reached in the next few years by large-scale laser interferometric detectors [3–5]. A comprehensive overview of gravitational wave detection can be found in two recent books [6,7].

At 15:02 (GMT) on 02 March 1989 two prototype gravitational wave detectors, one operated by the University of Glasgow (UG) and the other by the Max Planck Institute for Quantum Optics (MPQ), participated in a joint observing run over a period of 100 hours. The motivations for this run were twofold. First, to demonstrate the practicality of making long-term coincident observations with interferometers; and second to provide real data with all its inherent complexities for testing out a range of signal analysis programs. This was the first time that two interferometers had been run in coincidence for such a length of time. The

PII S0375-9601(96)00438-0

5. The analysis software

The 100-hour experiment was undertaken with a view to gaining practical experience under realistic conditions and offering guidance for the development of larger detectors. This motivated our decision to analyze the data with computer programs that could serve as prototypes of programs that will have to process the data of the large interferometers in real time. This software, designed by the Cardiff group, is described in detail in a Ph.D. thesis [14].

A search for continuous gravitational waves using the Allegro detector

E. Mauceli, P. Elcan, W. O. Hamilton, W. W. Johnson, M. P. McHugh, and A. Morse

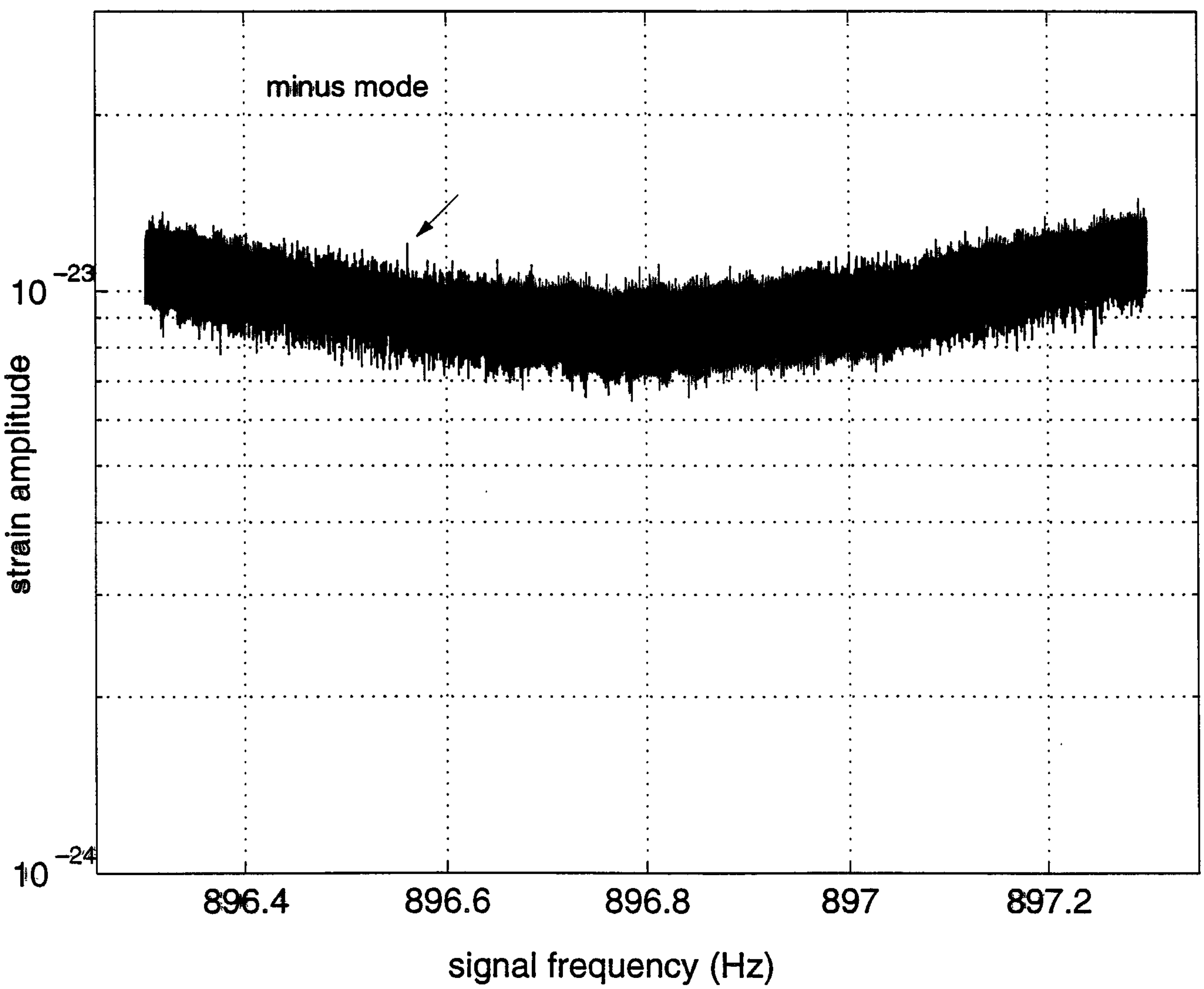
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA

(October 3, 1997)

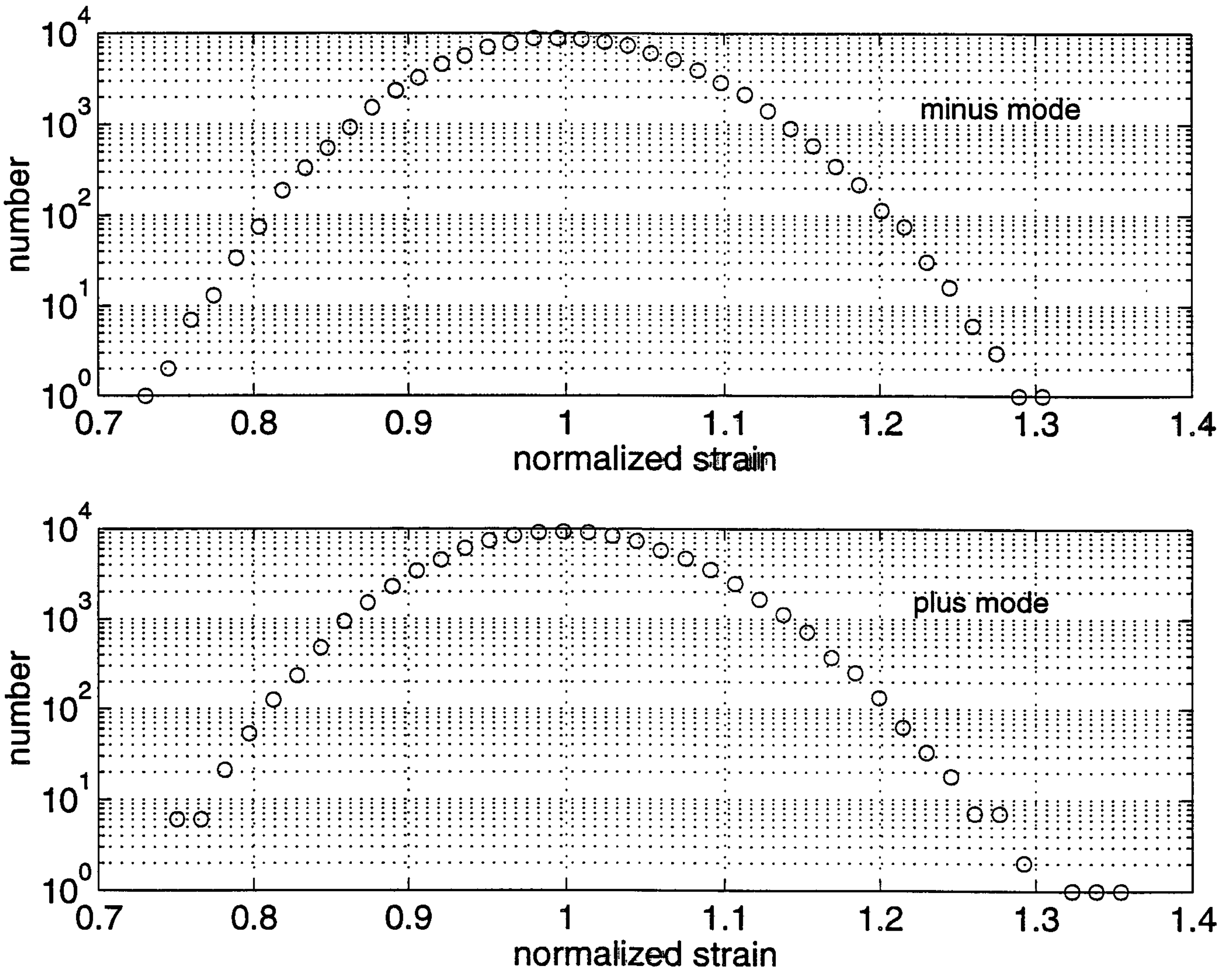
Abstract

We describe the results of a first search for continuous wave radiation by the Allegro gravitational wave detector using data taken in early 1994. Such radiation might be emitted from a rotating asymmetric neutron star. The search was directed towards both the galactic center and the globular cluster 47 Tucanae. A number of candidates from 47 Tucanae are identified but no detection can be claimed. The results put an upper limit on the gravitational wave strain amplitude of $(3-7) \times 10^{-24}$ in two narrow frequency bands near 900 Hz.

04.80.Nn



minus mode
strain amplitude
10^{-23}
10^{-24}
896.4
896.6
896.8
897
897.2
signal frequency (Hz)



minus mode
number
normalized strain
plus mode
number
normalized strain

Angular Sensitivity

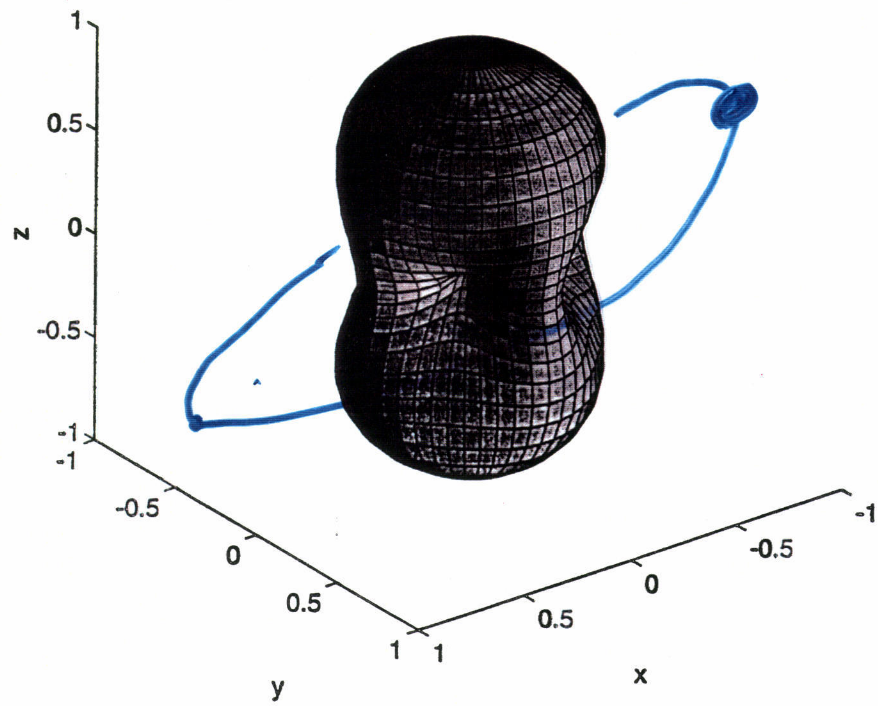
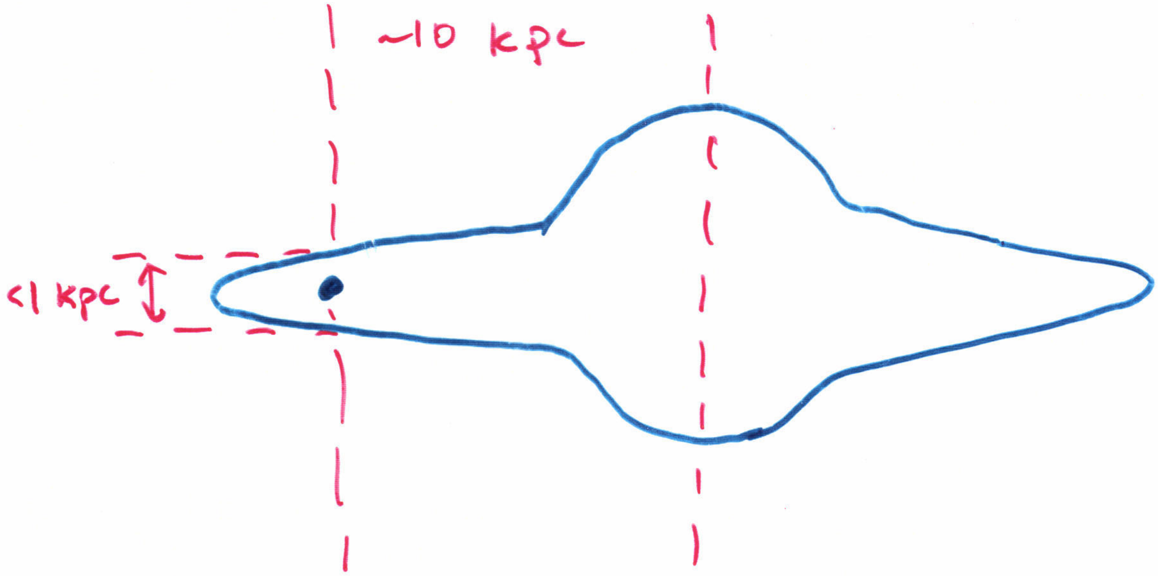
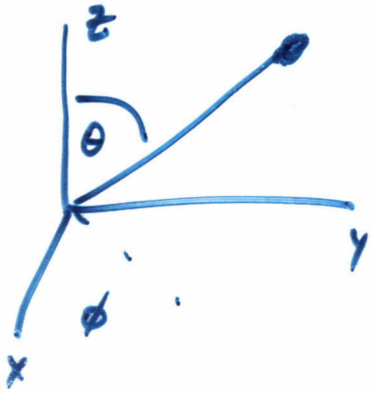


Figure 2.7 The sensitivity, as a function of direction, of an interferometric gravitational wave detector to unpolarized gravitational waves. The interferometer arms are oriented along the x and y axes.



Assume a real "signal" - added noise - from galactic center

Fit to detector angular sensitivity as Earth rotates



Measure $P(\theta, \phi)$ - noise power
~ 4 day run

Repeat measurement in $1\frac{1}{2}$ mon

Compare $\frac{P(\theta, \phi, T+45\ \text{days})}{P(\theta, \phi, T)}$

Long term outlook for the 40 Meter Interferometer

- Manpower requirements for LIGO installation are large.
- Major reconfiguration of the 40 M during LIGO installation and commissioning phases would probably exceed LIGO resources.
- Proposals for future use must not be resource intensive.

Conclusion

- The 40 M schedule will only modestly affect remaining LIGO design work.
- It can have a substantial effect on commissioning:
  - Provides the only operational experience we get before LIGO field deployment.
  - Input to development of procedures, operating software.
  - Inputs to software for diagnostic monitoring, data analysis.
- Requires "squeaky wheels" to make sure that 40m experience is communicated to the rest of LIGO.

NSF Spring report

- Much remains to be done, not only with modelling, but also with testing and training, particularly on the 40m system. When the 40m is again operational, LIGO can interactively test and refine their computer models as they move from a real 1 m system with fixed masses to a real 40 m system with suspended masses. This will be critical to the proper design of the alignment sensing and control tools for the 4-km system.