New Folder Name Interferometer Evolution

LIGO-T930013-00-D

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Facsimile Cover Sheet

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NUMBER OF PAGES (including this cover sheet): 8

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NOTES:

COPY OF E MAIL AND FIGURES DEVELOPED IN 1993 DEPICTING A MEANS FOR DETECTOR ENHANCEMENT FROM THE INITIAL DETECTOR

file:interfevol052893.txt
from: R. Weiss May 28,1993
concerning: Some thoughts on interferometer evolution

Enclosed are some thoughts and preliminary modeling of the gradual evolution from the initial interferometer to more advanced ones in the LIGO.

The accompanying curves are in terms of LIGO rms detection sensitivity including the factor of 10 detection inefficiency we have been using for source polarization and position uncertainty. The dotted lines are the optimistic (23Gpc), best guess (200Gpc) and pessimistic (1000Gpc) rms strain values for NS/NS binary coalescence for 3 events per year. The source strain has been rigged to include the sqrt(n), where n is the number of cycles in the waveform. The same technique used in our 1989 proposal. The equivalent noise curves are expressed as

h(rms) = h(f)*sqrt(f)

and may be pessimistic since this is not the optimal filtering but I don't expect to be off by more than a factor of 2 in amplitude.

Figure 1 shows the phase noise evolution with modest changes in the optics keeping the initial interferometer optical topology- a power recycled interferometer. The changes are made in the parameters of the arm cavities, increasing the storage time while reducing the mirror losses. The power on the beam splitter remains the same but the power in the arm cavities increases. The final curve shows the change from 8 watts raw laser power, which corresponds to eta * epsilon * P(laser) = 2W, the initial interferometer example, to a raw laser power of 20 watts. The important thing to notice is that the phase noise is not a hard driver on the interferometer development to detect the coalescences if one can reduce the other noise terms in the interferometer between 10 to 100 Hz. I think the major effort to allow the improvements shown in the figure will come from reducing the large scale figure errors in the cavity arm mirrors so that the losses and interferometer contrast defect will allow us to benefit from the low loss coatings and superpolished surfaces.

Figure 2 shows the evolution of the seismic isolation. I think this is the easiest part of the system to improve. The evolution shown is from our current Viton stack and a single pendulum suspension. The next improvement is (in this model) a double suspension (this is driven by the thermal noise from the final stage of the isolation system as will be seen in the figures on thermal noise). The third example improvement is a single low frequency stage in the isolation system with an outer stage at 1/5 Hz and a double pendulum. There is nothing unique in this example, it happens to be one that was incorporated in the gravenoise program used to make these plots and was a system we were working on at one time using a magnetically suspended outer stage. The benefit from a suspension point interferometer should really be analysed for once, it may do even better.

Figure 3 is an estimate of the thermal noise budget of the initial interferometer. The model assumes structure damping for all systems except the final stage of the isolation system which, because of the elastomers, is closer to viscous damping. The pendulum thermal noise is smaller than in the proposal because struture damping rather than viscous damping is being modeled. The cross coupling of vertical to thermal noise due to Earth curvature and deviation from interferometer plane level is assumed 6 x 10^-4.

Figure 4 shows a thermal noise evolution from the initial interferometer. The first thing done was to make the pendulum a double suspension to reduce the noise from the isolation system final stage. This now looks like overkill. The second stage pendulum thermal noise is improved by changing the Q. The final step is made by changing the mass of the mirror in this example. The unyielding part is the thermal noise from the internal mirror modes. The model assumes direct coupling to the interferometer by modes which cause an average length change of the cavities and uses a derating of 10^-2 for those modes that, if the beam is centered, would not contribute in first order. The structure damping hypothesis clearly makes the projection more pessimistic

than what we have used before and makes the understanding of internal modes of the test masses a major research area for advanced interferometers.
If there is time between now and the meeting I will make more exact models of the noise from the internal modes. In particular, I have not been careful with changing the resonance frequencies with the mass, the final step in the progression.

These figures are intended to belabor the obvious, improvements in our ability to detect coalescing binaries comes from low frequency improvements in the interferometer and these come from improved suspensions, isolation systems and, most important, reduction in the thermal noise. The improvements in the optics and changes in the optical topolgy are far less important in enhancing our chance of detecting the (over advertised?) binary coalescencess. This modeling once again shows that it would be a mistake to reduce the length of LIGO arms.

file:gwrms053193.txt
from: R. Weiss
concerning: Thermal noise projections for advanced interferometers

The file gwrms5.ps is a postscript file ready for printing that should replace figure 4 of the mailing to you on projections of how the initial' interferometer could evolve to the advanced interferometers. The new figure uses in the last improvement an internal mode Q of 30million. In a discussion with Kip last Saturday, he quotes Braginsky as saying this is a reasonable value for fused quartz test masses.
The curves in the figure are then:

1) Final isolation stage thermal noise filtered by a double suspension: final stage parameters ;Q =3, m = 80kg, pendula 2* 10kg at 1 Hz .

2) Final pendulum stage m= 10kg pendulum Q = 1 x 10^6 all structure damp.
3) 10kg 1 x 10^7
4) 10kg 1 x 10^8

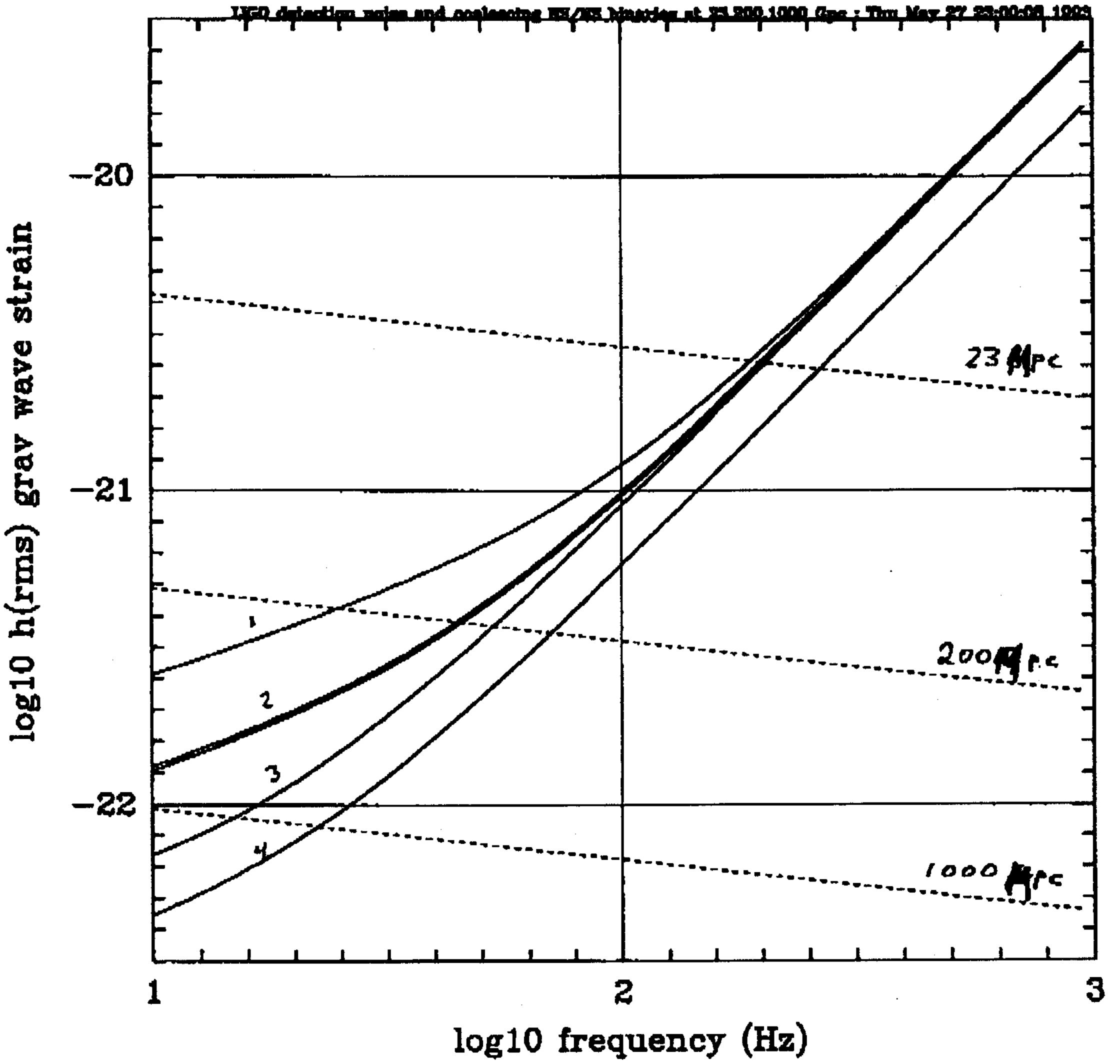
5) Mirror internal mode 10kg mode Q = 1 x 10^5 all structure damp.
6) 10kg 1 x 10^6
7) 10kg 3 x 10^7

Mass scaling:
Strain noise from internal modes scales 1/m^1/6
pendulum 1/m^1/4 to 1/m^1/2 depending on flexure geometry
Strain noise from quantum limit 1/m^1/2

Dotted lines are the NS/NS coalescence amplitudes multipled by sqrt(n) for 3 events/yr: top line 23Gpc, middle 200 Gpc, bottom 1000 Gpc.

Note to Kip; You will find another factor of 2 we forgot on Saturday in the conversion from delta L/L to strain h.

FIGURE 1



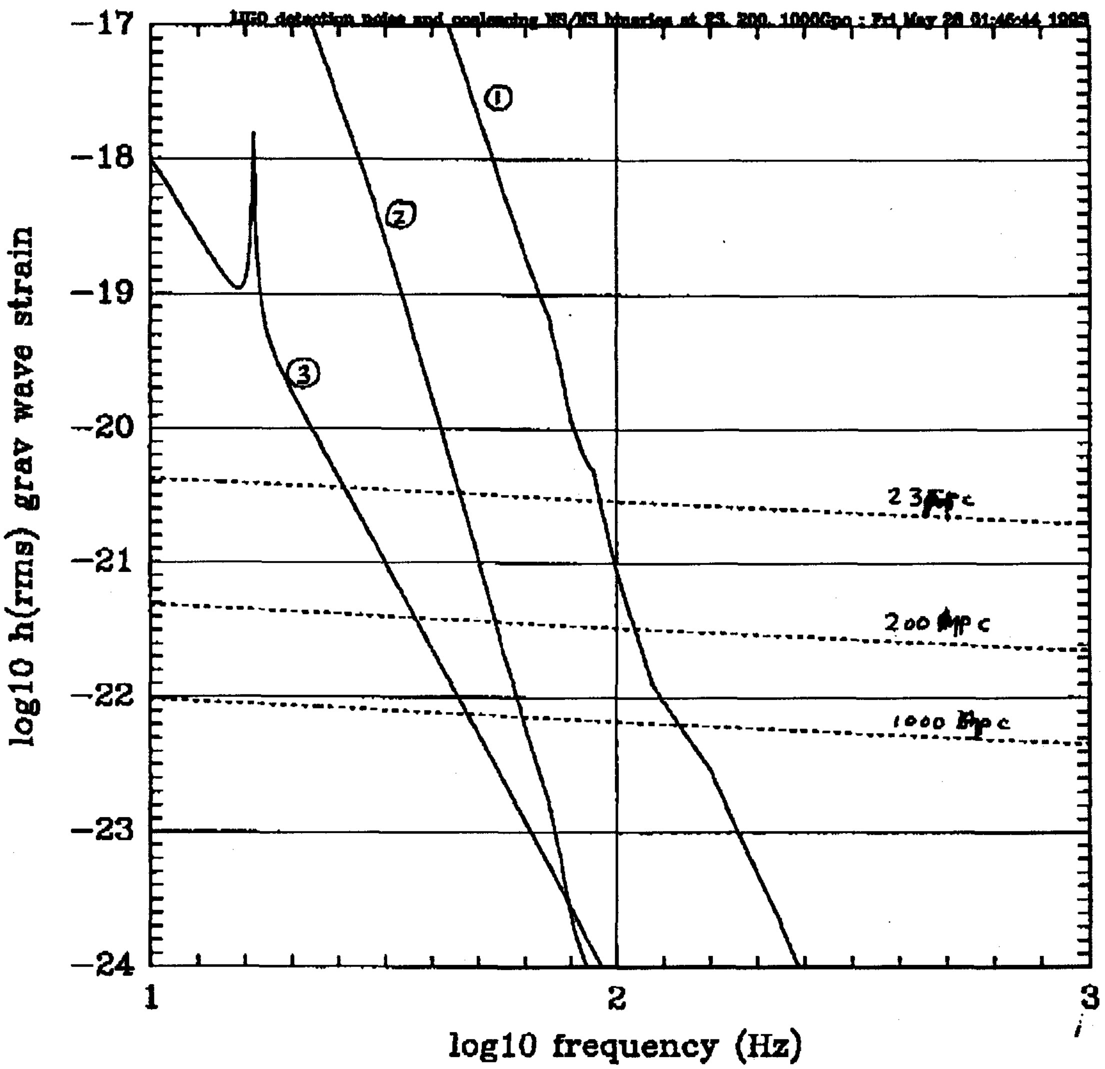
~~PH~~ PHASE NOISE EVOLUTION FROM INITIAL INTERFEROMETER

VALUES	$\tilde{S}_{ST}/\tilde{S}_{T}$	A_{M}	P_{LASER}	$\eta\,\epsilon_{OPT}$	C	$P_{CAV\,AIR}$	P_{BS}
INITIAL 1	66	1×10^{-4}	8.3	0.24	.999	5.3 KW	82 W
2	132	5×10^{-5}	8.3	0.24	.999	10.7 KW	82 W
3	264	2.5×10^{-5}	8.3	0.24	.999	21.4 KW	82 W
4	264	2.5×10^{-5}	20.0	0.24	.999	51.6 KW	200 W

POSSIBLE OPTICAL EVOLUTION OF INITIAL INTERFEROMETER IN EARLY STAGES OF THE LIGO ~~[illegible]~~ OF NOISE CHANGES IN THE OPTICS AND FINAL CHANGE IN LASER OUTPUT POWER

Gwfms2.ps

FIGURE 2



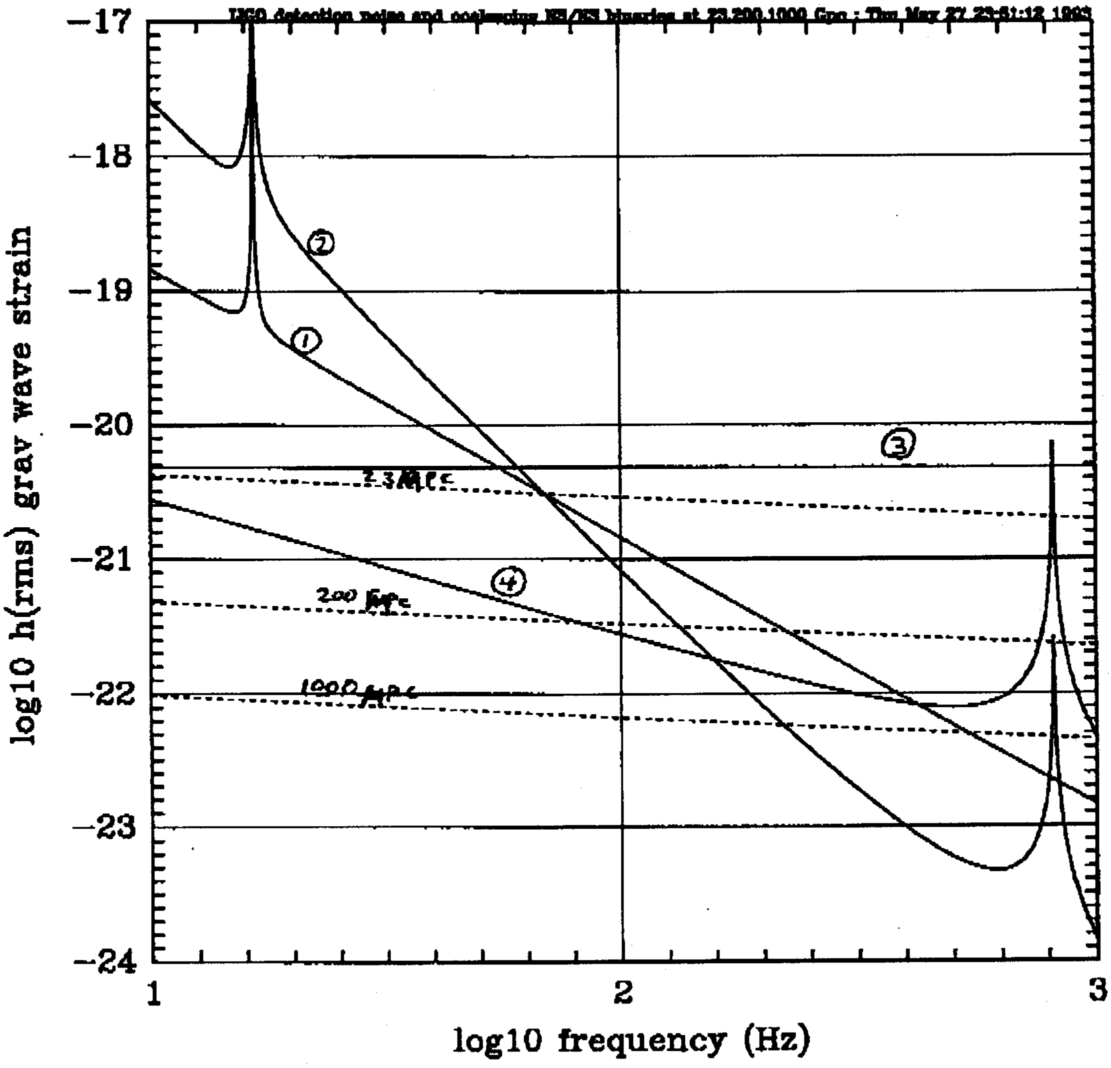
SEISMIC NOISE EVOLUTION FROM INITIAL INTERFEROMETER

① VITON STACK SINGLE PENDULUM 1 HZ (INITIAL)

② VITON STACK DOUBLE PENDULUM $(1\ Hz)^2$

③ 3 STAGE 1/5 HZ, DOUBLE PENDULUM $(1\ Hz)^2$
METAL / OR MAGNETIC INITIAL STAGE

gwrms6.ps



THERMAL NOISE INITIAL INTERFEROMETER $m = 10Kg$

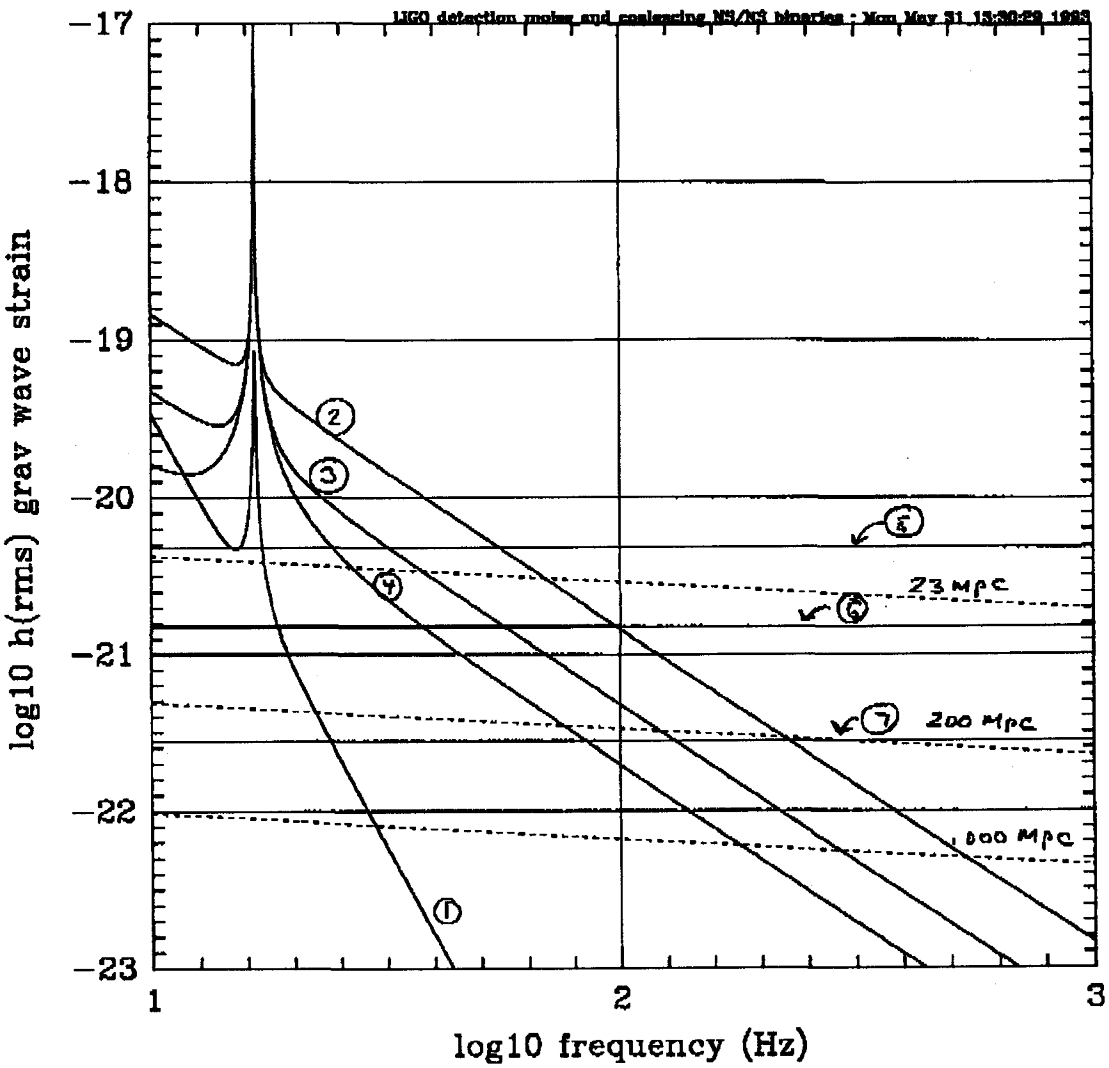
① PENDULUM THERMAL NOISE $Q_p = 1 \times 10^6$ STRUCTURE DAMPED

② FINAL STAGE OF ISOLATION $Q \sim 3$ $m = 80Kg$ VISCOUS DAMPED 1 PENDULUM STAGE

③ INTERNAL MIRROR MODES $Q = 1 \times 10^5$

④ WIRE THERMAL NOISE $Q = 1 \times 10^4$ VERTICAL MOTION

gwrms3.ps



THERMAL NOISE EVOLUTION

① FINAL STAGE OF ISOLATION SYSTEM WITH DOUBLE PENDULUM
$Q = 3$ $m = 80$ Kg $2 * m = 10$ Kg $Q_p \sim 10^5$

② FINAL PENDULUM STAGE $m = 10$ Kg $Q_P = 10^6$ STRUCTURAL DAMP

③ FINAL PENDULUM STAGE / 10^7 /

④ FINAL PENDULUM STAGE / 3×10^7 /

⑤ MIRROR INTERNAL 10Kg 1×10^5 STRUCTURAL

⑥ MIRROR INTERNAL / 1×10^6

⑦ MIRROR INTERNAL / 3×10^7 (BRAGINSKY ESTIMATE