Laser Interferometer Gravitational Wave Observatory (LIGO) Project
Advanced LIGO

Technical Memorandum	LIGO-T000091-00-D
To:	LIGO-2 Systems Group
Author:	Dennis Coyne
Date:	9/6/00
Title:	**Minutes: Advanced LIGO Systems Meeting (9/1/00)**

General notes regarding the Systems Meeting:
An advanced LIGO ad hoc systems group has been organized, particularly for the proposal development (but it would have a life beyond the proposal, until an advanced LIGO organization is actually established). The membership as meant to capture people involved in systems issues and a representative form each subsystem. Current members and their principal (though not sole) areas of contribution are as follows:

Rolf Bork	DAC & electronics & embedded controls
Jordan Camp	Lasers & optics
Dennis Coyne	systems
Peter Fritschel	systems
Joe Giaime	SEI
Eric Gustafson	Lasers & optics
Norna Robertson	SUS
Bill Kells	COC
Peter King	PSL
Albert Lazzarini	LDAS
Dave Reitze	IO
Gary Sanders	systems
David Shoemaker	systems
Ken Strain	AIC
Mike Zucker	ISC

We plan to have **bi-weekly meetings on the 2nd and 4th Fridays of the month at 8:30 am PT**. First order of business is to establish the trade studies that need attention and definition of the reference design parameters (or constraints/bounds on some of these parameters). An Advanced LIGO systems web has been established to document the evolving reference design:
http://www.ligo.caltech.edu/~ligo2/scripts/refdes.html
These minutes and other data of interest to the systems group will be published on the LIGO-2 web pages in the future.

Minutes of the first meeting:
Three topics were on the agenda for the meeting.

1. Test Mass size and weight

A 30 kg test mass was originally chosen but somewhat arbitrarily. It may be possible to obtain 40 kg sapphire or fused silica test masses.

Dennis Coyne under separate email (due to procurement sensitivity to costs) sent out a very rough estimate of the possible additional costs for a 40 kg sapphire test masses rather than 30 kg sapphire masses. The bottom line is $1.5M to $2.0M. *However*, the assumptions that went into the estimate need to be confirmed with Crystal Systems; Jordan Camp will do this when his contact returns from travel. *(9/6 follow-up note: Preliminary response is that the cost does depend on test mass volume (it's not just a per boule cost) and a quantitative estimate of cost impact should be provided on or about 9/15)*

Ken Strain presented comparisons of strain sensitivity for 30 kg and 40 kg Sapphire and Fused Silica test masses, based on the Bench code with the new, correct quantum noise, and only lacking a correct fiber/ribbon model. The resulting strain sensitivity plots are attached. Ken scaled the beam diameter and the mirror dimensions by $(40/30)^{1/3}$. The thermal noise optimum might be slightly different from what is shown. Ken also notes that it might be possible to develop an RF sensing scheme that gives slightly less radiation pressure noise, by a factor of Sqrt[2], at around 30 Hz.

Ken also used the latest Melody release to compare sapphire and silica systems with various ROC mirrors needed to get the beam size that minimizes thermal noise. These results, while preliminary, are noteworthy. Thermal lensing and thermo-elastic effects are now included, as well as aperturing. Results are just a little different from earlier versions of Melody that included only thermal lensing. This modeling was done with <u>no</u> thermal correction applied.

Ken used RF sideband stability as a guide to the extent of the thermal distortion. We can relate this to LIGO I where the optimum is around 6W input. (Remember that we have different materials, finesses and recycling factors.)

The results are summarized in the following table.

Material	ROC-ITM=ROC-ETM (km)	spot rad (cm)	highest power (W)
Silica	36	5.5	8
Sapphire	36	5.5	18
Sapphire	50	5.9	13
Sapphire*	45/55	~5.9	13

Notes:

- <u>Silica</u>: beamsize appropriate for 30 or 40 kg; thermal lensing serious so don't use larger beams (advantage would be small)
- <u>Sapphire</u>: always 80ppm/cm absorption assumed
- <u>Sapphire</u>: 36km best for 30kg mirror
- <u>Sapphire</u>: 50km approx. best for 40kg mirror (not optimized, however)
- <u>Sapphire*</u>: this is a preliminary result of a single test with one ITM and one ETM having 45km and 55km rather than the correct 50km. There was remarkably little difference from the case with 4 50km mirrors. This has to be rechecked and explored further before making any conclusion.

There might be a price to pay in the shot noise for using 40kg sapphire to reduce thermal noise and radiation pressure (RP). This would result in a slight narrowing of the bandwidth of the optimum NS:NS detector. (The laser power might be reduced to ~13/18, or alternatively better thermal compensation would be needed.) Note that this factor is still small compared to uncertainty in sapphire parameters.

Eric pointed that if one allows for going to even higher laser power, then the performance comparison between 30 & 40 kg can be larger, since thermal noise is more dominant.

Summary: The gain in going from 30 kg to 40 kg sapphire test masses is only about 10%, and this may be difficult to achieve (requiring better thermal compensation or higher shot noise (lower laser power)).

The suspension group was asked to comment on whether there was any significant technical drivers for them regarding a decision on a 30 kg or 40 kg test mass. Norna indicated that this has not yet been examined and that it may take considerable effort to make a careful trade study. A cursory examination of the design was requested to see if the change from 30 to 40 kg would cross a technical barrier/threshold and make the suspension design much easier or much more difficult.

The decision as to whether we use 30 kg or 40 kg in the reference design is deferred to the next meeting.

1) *Action: Jordan Camp to get sapphire cost planning data from Crystal Systems for 30 kg and 30 kg sapphire test mass blanks.*
2) *Action: Norna Robertson to perform a cursory examination of the suspension design to see if the change from 30 to 40 kg would cross a technical barrier/threshold and make the suspension design much easier or much more difficult*
3) *Peter Fritschel to look at the performance advantage of higher test masses (40 kg vs. 30 kg) at higher laser power with a version of bench that includes the correct quantum noise.*

2. Non test mass optic sizes

The attached table, of proposed non-test-mass optics sizes (e.g. SRM, PRM, MC, etc.), was distributed by Norna Robertson in advance of the meeting.

FM Size.

Norna proposed a common FM and BS optic size in the hope of reducing the number of unique suspension designs. However, GariLynn pointed out that the ~40 layer dielectric HR coating on the FM would too much coating strain induced distortion of a thin (BS) optic. It was decided to have separate FM and BS optic sizes.

Mode Cleaner Mirror Size and Isolation.

Peter summarized the email discussion of the preceding week: We agreed to avoid any choices at this time, which would compromise the performance of an RF readout system (i.e. we will not assume that a DC readout scheme will be the final design). However this does not appear to have a large impact on the mode cleaner design. The mode cleaner stability requirement should be viewed as fairly soft, because we have the additional stabilization of the arm cavities following it. If the test masses are eddy-current damped, then there is no feedback to them required from the common mode error signal, and we can get very large frequency suppression at 10 Hz. We assumed a factor of 1000 in the presence of the DC readout, but it could go a factor 10 higher surely, consistent with the RF readout.

Also, I'm not comfortable that we will be able to reach a laser RIN of 1e-9/rHz at 10 Hz, and think we should consider that 'only' 3e-9/rHz is reached.

So I think we should be guided by making the MC requirements relatively easy to achieve, but not give away performance if there are no practical benefits to it.

- Isolation & noise: We have already increased the HAM suspension noise to 3e-17 m/rHz per mirror at 10 Hz; this would give a 16.6m MC frequency stability of 7e-4Hz/rHz @10Hz, so it is good enough. It could be loosened up further (as this is up to a factor of 10 lower than radiation pressure), but I am told that there is no practical benefit to changing from a triple suspension to a double, so I think we should leave this requirement as is. Note that this is with the local damping ON.
- Mirror size: A 20x10 cm (7kg) sounds a bit large for ease of handling, etc. I think the suspension folk should feel free to consider smaller sizes if they think it makes for a better design. I'd propose we set a mass range of 3 - 7 kg, and the suspension folk can choose within that.

Given this range of mass and assumed laser RIN, the MC frequency noise at 10 Hz would be 6e-4 to 4e-3 Hz/rtHz, comfortable for either DC or RF readout, I think.

The suspension group will consider this suggested mass range and propose a value with which they are comfortable; Probably 7 kg and a diameter of 20 cm. Ken Strain indicated that with the relaxed requirements it may be possible to use steel wires instead of fused silica fibers, but there would be no margin in the design – silica fibers will continue to be the reference design.

RM Size and Isolation

Peter summarized the email discussion of the preceding week: I recommend continuing with the noise requirement of 3e-17 m/rHz at 10 Hz; it may very well be possible to relax it some given the direction the interferometer configuration has taken, but let's hold that possibility in reserve. Given the 1e-13 m/rHz prediction for optics table motion at 10 Hz, this means 3e-4 of isolation (local damping on).

For size, it doesn't seem sensible to continue with the notion that they are just the same size as the test masses, since the latter will be in flux for a while, and it doesn't make sense to have the RMs follow the more stringent requirements of the test masses. So Ken and I took the approach of considering the largest beam size that we are contemplating -- 6 cm radius -- and finding the diameter for which there is 100 ppm of diffraction loss. This gives 25.4 cm diameter.

Mode Match Telescope mirror #3 (MMT3)

The last element of the mode matching telescope needs to be as large as the RM and so it needs to be added to Norna's table of suspended large optics.

Reaction Chains

All vertex large optics (except the FMs) should have reaction chains to the penultimate mass. The BS, SRM, PRM, ITMs and MMT3 need ~1 Hz bandwidth control (alignment and axial[⊗]). The FMs just need pitch and yaw bias controls, no active alignment control. Reaction masses are only needed for the curved mode cleaner mirror (MC2). The suspension group hopes to use eddy current (passive) damping.

4) *Action: Norna Robertson to revise and re-distribute the table of suspended optic sizes.*

[⊗] Note: A ~1 Hz control bandwidth for axial motion was proposed by Peter Fritschel at the 8/8-11/00 LIGO-2 Systems meeting at MIT. Further analysis is required before this is adopted as a baseline requirement.

3. Laser beam elevation: SEI table heights

There is not much height above the optics tables in the HAM chambers. In order to proceed with suspension designs for the optics in the HAM chambers the laser beam elevation in the HAM chambers and the HAM optic table elevations must be established. A number of factors need to be considered in order to set the laser beam elevation:

- HAM chamber height vs. position/area, parameterized by optics table height
- MC and RM suspension heights and required planform areas.
- Viewport window height for MC reflected and transmitted optical signals and RC reflected port signal.
- Refraction through RC optic wedges (horizontal or vertical)
- Beam position limits within the BT for diffraction and backscatter
- Nominal MC length (position of the suspensions within the HAM chambers)
- Nominal RC length (position of the suspensions within the HAM chambers)
- Allowable elevation range for the HAM SEI system

Not all of these factors have been addressed as yet. In addition, Dennis found an error in his write up which addresses the first of these factors (T000087-00) that needs to be corrected.

5) *Action: Dennis Coyne to revise and re-distribute the HAM available height memo.*
6) *Action: Dennis Coyne to address the other significant factors above and propose a laser beam elevation.*
7) *Action: Norna Robertson to define MC and RM (at least) planform dimensions for use in more detailed layouts of the MC and RC.*
8) *Action: Dave Reitze is going to work on the in-vacuum input optics layout, given the planforms from Norna.*
9) *Action: Dennis Coyne is going to work on the recycling cavity optics layout, given the planforms from Norna.*

4. Other Issues for Future Meetings:

A couple of topics were mentioned that have been deferred for discussion at future meetings.

Sapphire versus Fused Silica

The relatively similar sensitivities of the fused silica and sapphire test masses in the attached plots raised concerns that we are not philosophically approaching sapphire, or the sapphire-to-silica comparison, properly. We hope to develop sapphire as a better alternative material to fused silica for test masses. As such, we should not use the pessimistic expectations of the absorption that we can currently obtain (~80 ppm/cm), but a realistic goal in absorption that might be achievable through the material development program (~20 ppm/cm). In the comparisons between sapphire and fused silica, we have used the very highest Q values observed in fused silica (but only once in an uncoated piece), even though there are concerns that coating losses may significantly reduce the effective Q (and perhaps reduce the Q more for the lower stiffness fused silica optics than for sapphire optics). In addition, although we do not have a demonstrated ability to achieve active thermal compensation, if a “not unrealistic” expectation in potential thermal compensation allows us to take advantage of the reduction in thermal noise and radiation pressure noise for sapphire, we should not dismiss it. Given our considerable experience with fused silica, and lack of experience with sapphire, we may also want to ‘baseline’ fused silica for the advanced LIGO proposal and consider sapphire a possible alternative. Clearly we need some guidance on how to intelligently account for all of these uncertainties when we project advanced LIGO performance or make comparisons between sapphire and fused silica.

10) *Action: Dennis Coyne to propose an approach to the evaluation of sapphire and fused silica test masses, and comparisons between them, in the proposal for discussion at the next meeting.*

10 Hz cutoff for Suspensions:

[Question discussed briefly at the meeting and then framed by Norna in subsequent email:] What frequency should we aim to put the highest vertical mode of the ETM/ITM suspensions at? If there is not a lot to be gained in terms of binary coalescence distance at low frequency where radiation pressure looks like the dominant noise source, do we need to be pushing so hard to get the suspension thermal noise down to 10-19 m/rtHz all the way to 10 Hz? This is something which will I believe need input from the astrophysicists, since binary coalescences are not the only measure of the desired bandwidth. We made an effort last December to come up with a suspension design able to extend down to 10 Hz - involving going for very thin ribbons, long final stage and heavy upper mass. The design could be eased considerably if 10 Hz is no longer the target (or if the chosen power parameters etc are such that radiation pressure dominates at 10 Hz by a considerable margin and still dominates to maybe 20 or 30 Hz).

Beam Tube Backscatter and Core Optics Superpolish

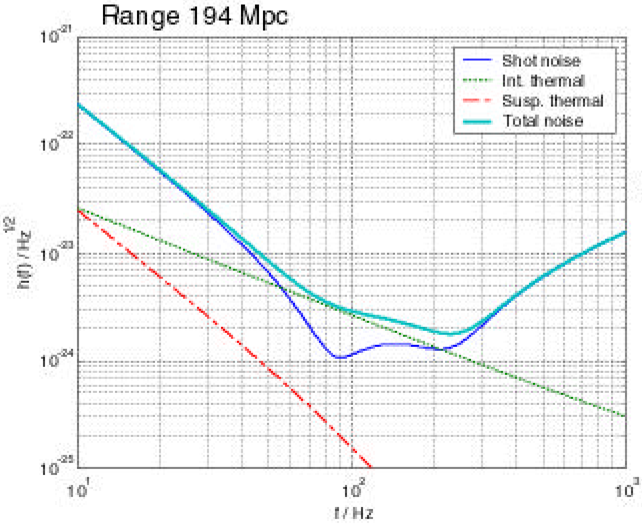
Albert Lazzarini recalls that the beam tube baffle BRDF performance was based upon an assumed improvement in the superpolish (microroughness) of future core optics. It was recommended that this be re-visited for advanced LIGO.

Comparison made using model for DC sensing scheme.

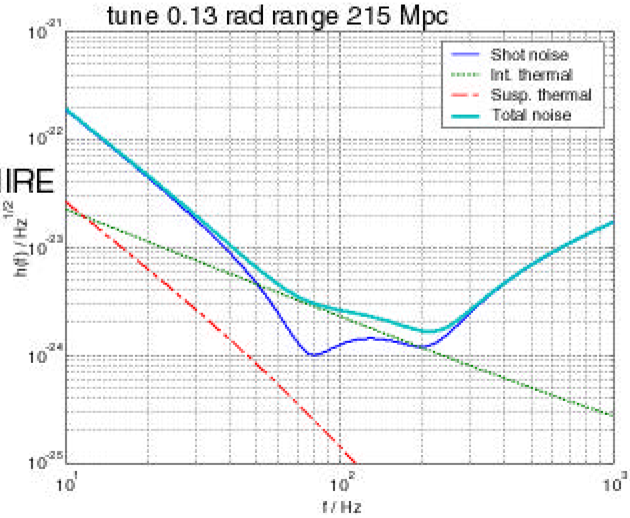
30 kg

40 kg

Range 194 Mpc

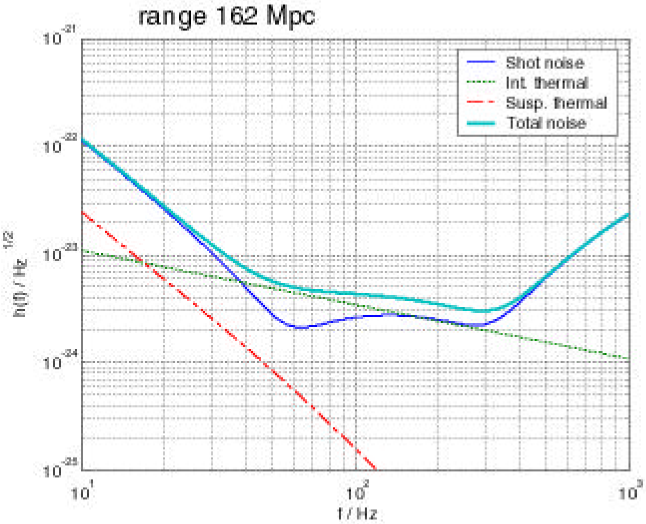


tune 0.13 rad range 215 Mpc

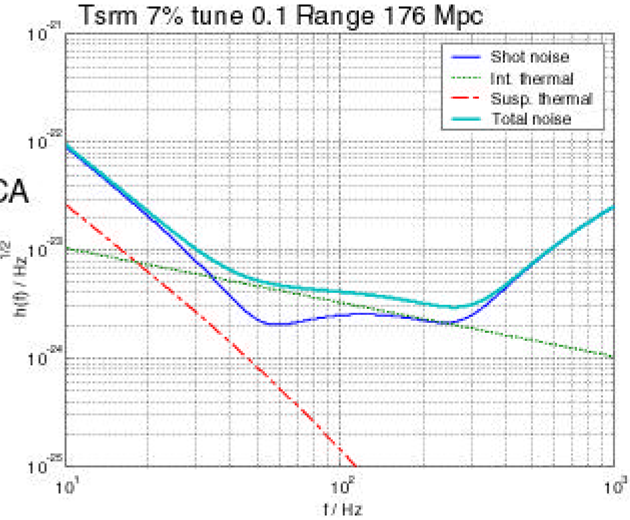


SAPPHIRE

range 162 Mpc



Tsrm 7% tune 0.1 Range 176 Mpc



SILICA