40m Upgrade Plans

- Primary goal of 40m upgrade
- Potential secondary goals
- 40m infrastructure upgrade
- RSE optical configuration
- Fundamental noise
- RSE control scheme
- modelling
- people, milestones
- problems and questions

PAC8 Meeting, May 1-2, 2000, Caltech

Alan Weinstein, Caltech

LIGO-G000134-00-R

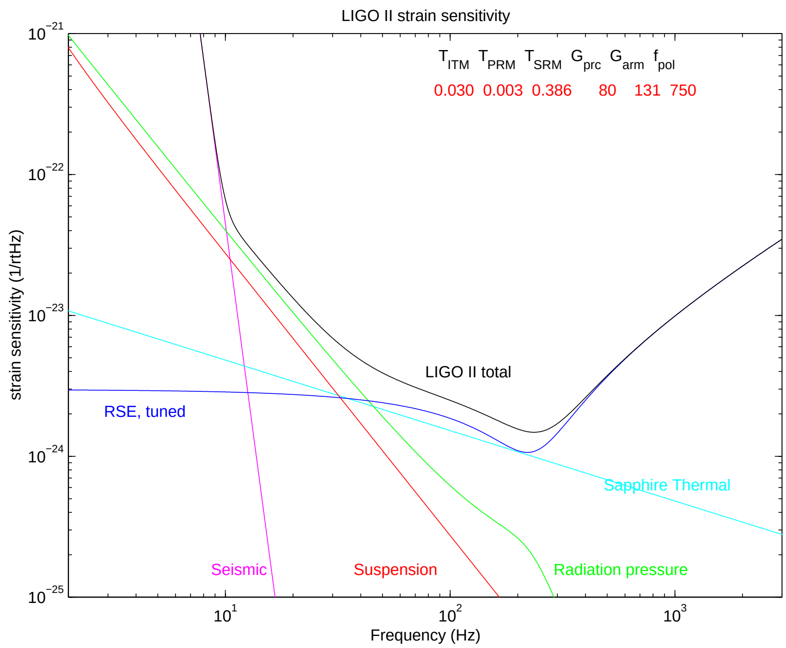
http://www.ligo.caltech.edu/~ajw/ligopac8.pdf

Review of 40m upgrade goals

- The primary goal of the 40 m upgrade is to demonstrate an advanced optical configuration to optimally tune IFO shot noise sensitivity.
- Optical scheme: resonant sideband extraction (RSE), in either broadband or tuned configuration.
- RSE and DR have been demonstrated at Garching 30m, and at several table-top IFOs
- An RSE/DR config appropriate for LIGO will be demonstrated at the Glasgow 10m by 2002.
- For LIGO, need a full engineering prototype, using LIGO electronics and control scheme. This is the primary goal of the 40 m upgrade.
- Complements work at other R&D facilities

Other LIGO II R&D Facilities

- Complements work at other R&D facilities:
  - 40m will focus on shot (phase, sensing) noise, high-f
  - LASTI: full-scale SEI,SUS prototyping; low-f
  - TNI: thermal noise; middle-f
  - ETF: Sagnac, high powered lasers



For prototyping full optical configuration, sensing, and controls system, need:

- suspended-mass IFO with power and signal recycling,
- LIGO-like infrastructure (as much as possible)
- in some proximity to LIGO-II engineering.

40 Meter is obvious choice.

Secondary 40m upgrade goals

Prototype "everything"?

- potentially, multiple pendula SUS
  — this may be necessary, to extrapolate experience gained at 40m to LIGO-II
- potentially, advanced SEI systems
  — scaled down, of course. Cannot replace full-scale testing at LASTI.
- LIGO-III: cryogenic TMs, QND, *etc.*.

At the least, must prototype everything that has large impact on electronics/control system, for a meaningful full engineering test!

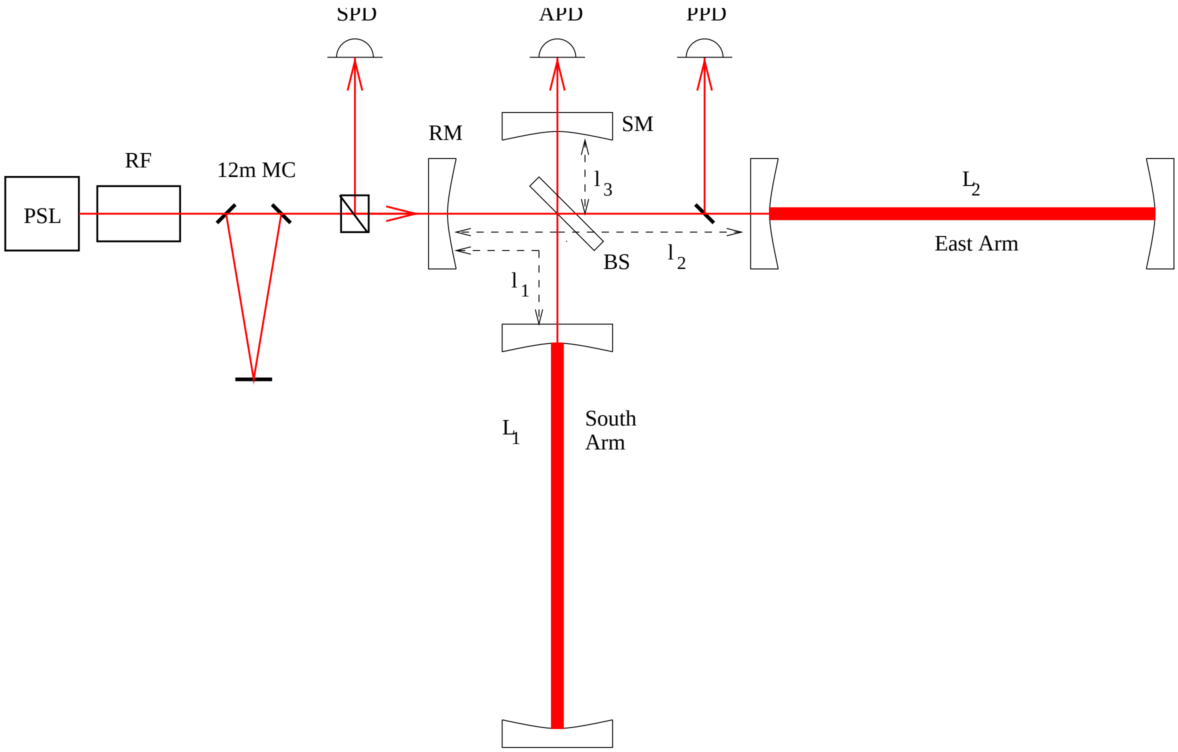
40M INFRASTRUCTURE UPGRADE

- LIGO-like upgrade, during next 1-2 years:
  - building modifications, control room, electrical
  - EPICS-based vacuum control system
  - LIGO-I PSL
  - 12m suspended mass mode cleaner
  - 4” optics for IR running
  - scaled (for 4” optics) suspensions
  - full CDS control system: ISC, LSC, ASC, GDS
- And then beyond, to LIGO-II:
  - Output chamber for signal mirror
    (chamber exists, seismic stack being built)
  - 7th suspended optic (SM)
  - control scheme for all optics
  - strawman: frontal mod with M-Z IFO
  - $\rightarrow$ LIGO-II-like SUS, SEI?
- Ready to prototype an RSE scheme by 2002.

40m upgrade

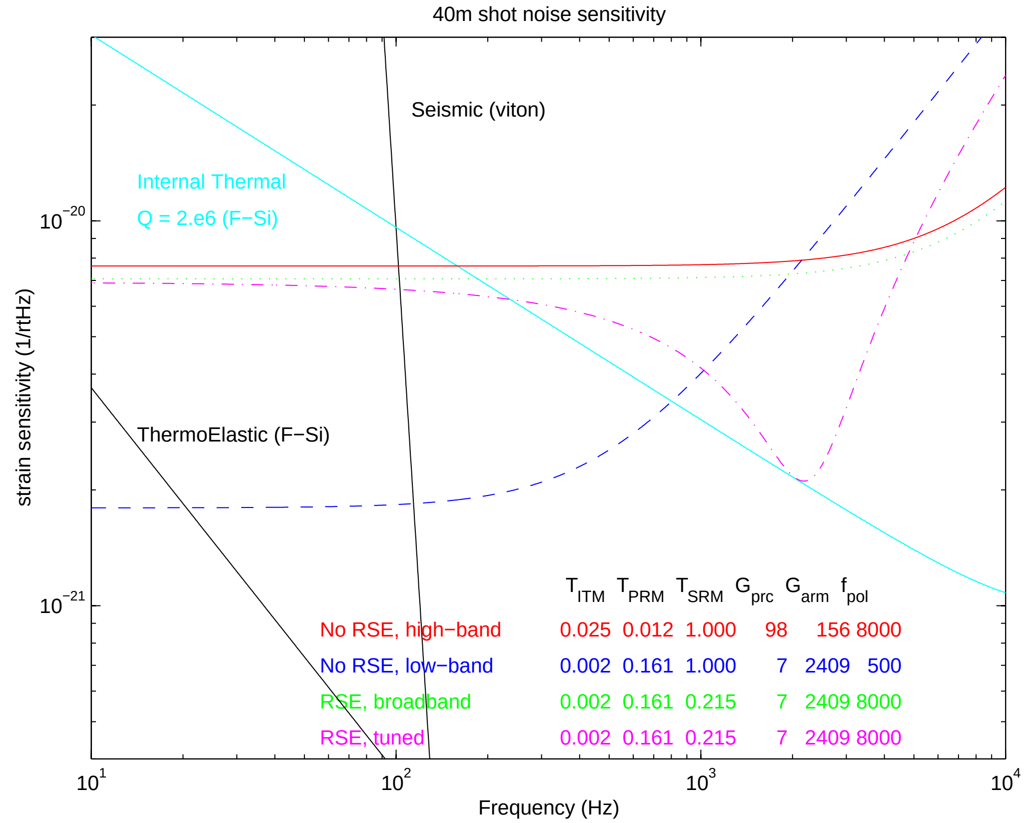
- Big outstanding questions:
  - Bake out entire vacuum envelope?
  - Add active seismic isolation to existing passive seismic stacks?
  - replace existing seismic stacks with LIGO-II prototypes?
- Work closely with RSE and multiple pendula development at Glasgow and elsewhere
- Work closely with LIGO-II SEI team
- The 40m laboratory will continue to be used for testing and staging of other LIGO detector innovations; physicist training; and education and outreach.
- More information: http://www.ligo.caltech.edu/~ajw/40m_upgrade.html

Resonant Sideband Extraction (RSE) Config



A power-recycled Michelson IFO with Fabry-Perot arms, with a signal recycling mirror (SM) for resonant sideband extraction (RSE).

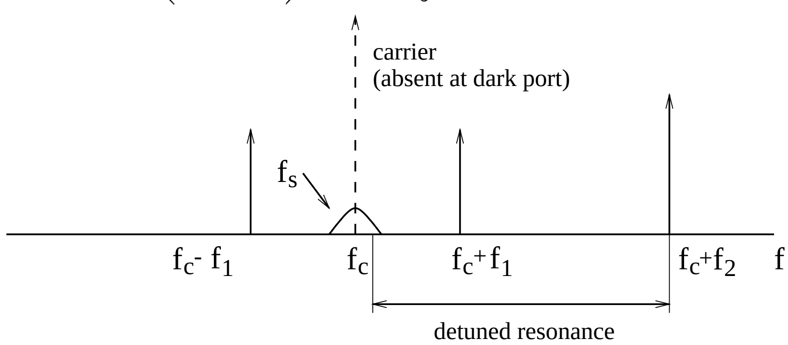
Fundamental noise at 40m



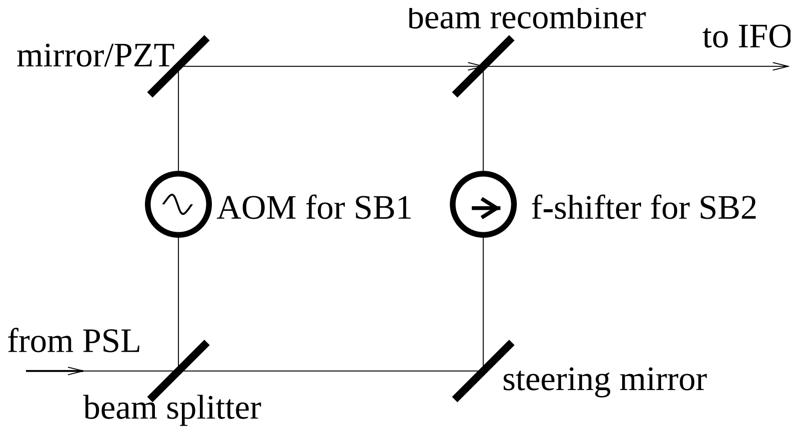
- Q (F-Si) $= 2 \times 10^6$
- Thermoelastic, photothermal noise are negligible
- Tuned config: $\nu_{cs} = 0.1$ ($\phi_{cs} = 0.63$ radians)
- Laser power turned down, to 400 mW
- Alternatively, live with thermal noise;
  don't bother to expose shot noise;
  focus on *controls* problem

Controlling the cavity lengths

- The carrier (C) and RF sideband (RF1) light is used to control the 4 relevant length DOFs for LIGO-I config: L_+, l_+, l_-, L_-
- The addition of one more cavity (SRC) requires additional sideband(s)
- Simple scheme (Jim Mason): single sideband (RF2) at $3f_{RF1}$



- applied via frontal modulation with input M-Z IFO



Controlling the cavity lengths

- L_+ (arms common) — $C/RF1$ In-phase, PRC PKO
- l_+ (PRC common) — $C/RF1$ In-phase, SPD
- l_- (PRC diff) — $C/RF1$ Qu-phase, SPD
- L_- (Arm diff, GW) — $C/RF2$ Qu-phase, APD
- l_s (SRC length) — $RF1/RF2$ In-phase, PRC PKO

Resonance conditions:

- Carrier resonant in ARMs, PRC
- Carrier resonant (broadbanded) or de-tuned in SRC
- RF1 resonant in PRC
- RF2 resonant in PRC, SRC

Cavity	arms	PRC	SRC
carrier	R_+	R_+	ν_s
SB1	A	R_-	A
SB2	A	R_-	R_-

TWIDDLE and E2E models in progress!

Optical Parameters

mirror	Loss (ppm)	$T = t^2$	R_{curv} (m)	ω_{beam} (cm)
ETMs	20	15 ppm	90.5	0.40
ITMs	20	1547 ppm	90.5	0.40
BS	750	0.500	∞	0.42
RM	20	0.161	60.3	0.42
SM	20	0.630	60.0	0.42

Arm cavity finesse = 3919

Arm cavity Gain = 2409

PRC Gain = 7.4

SRC tune $\phi_{cs} = 0.63$ rad

$h_{shot}(DC) = 4.4 \times 10^{-21}/\sqrt{P_l}$

$h_{shot}(2185Hz) = 1.3 \times 10^{-21}/\sqrt{P_l}$

Beyond RSE

Thermal noise:

- Thermoelastic noise scales like beam radius $r_0^{-1/2}$ while Brownian noise scales like beam radius $r_0^{-3/2}$, and beam radius $r_0 \sim L_{arm}^{1/2}$
- Need large beam radius, long IFO arms to measure thermoelastic noise at LIGO-II-like conditions; and to disentangle thermoelastic, Brownian, other
- With nearly flat mirrors, 40m can get within factor 2 of LIGO-II for Brownian, factor 5 for thermoelastic
- nearly unstable cavities will be difficult to align!

Seismic isolation:

- Advanced SEI systems (soft, hard) can be scaled to fit in 40m vacuum envelope, and can facilitate IFO operation, controls prototyping.
- Still need LASTI for full-scale prototyping; scaled-down prototyping at 40m may not be useful.

Additional work accomplished / in progress

- Detailed shot noise modelling
- variations on optical design
- Detailed seismic noise modelling
- Detailed thermal noise modelling
- cavity length optimization
- mirror radii of curvature, spot sizes
- 12m mode cleaner design
- Twiddle and E2E models
- FFT modeling (so far, perfect optics only)

People

- Currently: Two physicists (Weinstein, Ugolini), one master tech (Vass)
- Lots of summer REU's
- Hope to make heavy use of LIGO engineers: CDS, optical, mechanical
- Hope to involve more postdocs, grad students, undergrads

All LSC personnel are invited and encouraged to contribute and participate as much as possible!

Schedule, Milestones

- 3q2000
  - lab building repairs and mods
  - LIGO IR PSL
  - Construction of new Output chamber, stack
  - Bakeout? Retrofit existing stacks?
- 4q2000
  - Review of optical design consistent with RSE/DR
  - Development of control system
- 2q2001
  - LIGO-like suspensions, controllers, optics in place
  - LIGO-like CDS: ISC, LSC, ASC, WFS systems
  - LIGO-like diagnostics, DAQS software
  - Review of SM control scheme
    (broad-band and detuned)
- 2002
  - Prototype installation complete.
  - Initial shakedown complete.
  - Ready to prototype an RSE scheme.

Problems and questions

- Do we need to bake out the vacuum envelope?
- Should we retrofit the seismic stacks
  with active seismic isolators,
  reducing v_{rms} and thus mean time to lock?
  Pros: IFO will be much easier to lock!
  Cons: Cost, effort; maybe they won't work.
- should we consider prototyping advanced SUS systems (multiple pendula, electrostatic control)?
- Should we consider employing
  advanced (scaled down) SEI systems?
- Is the "simple" control scheme developed by Mason adequate for LIGO-II?
- How can we implement it? M-Z? $f_{RF2} = 100$ MHz?
  Will the signal mirror fit in vacuum envelope?
- where will we get the physicists and eng. support?