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

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.
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
A power-recycled Michelson IFO with Fabry-Perot arms, with a signal recycling mirror (SM) for resonant sideband extraction (RSE).
• $Q \text{ (F-Si)} = 2 \times 10^6$

• 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

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TWIDDLE and E2E models in progress!
## Optical Parameters

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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.
ADDIONAL 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?