40m Upgrade Plans

PRELIMINARY!

- Review of 40m upgrade goals
- 40m infrastructure upgrade
- RSE configuration - design considerations
- IFO optical configuration
- RSE control scheme
- people, money, schedule
- problems and questions

http://www.ligo.caltech.edu/~ajw/40m_lsc_300.pdf

LIGO-G000137-00-R, /home/ajw/Docs/G000137-00.pdf

Review of 40m upgrade goals

- The primary goal of the 40 m upgrade is to demonstrate a scheme for using resonant sideband extraction (RSE), in either broadband or tuned config, appropriate for an optimal LIGO config
- RSE and DR have been demonstrated at Garching 30m, and at table-top IFOs
- An RSE/DR config appropriate for LIGO will be demonstrated at the Glasgow 10m
- 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:
  - 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

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.*.
- physicist training

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

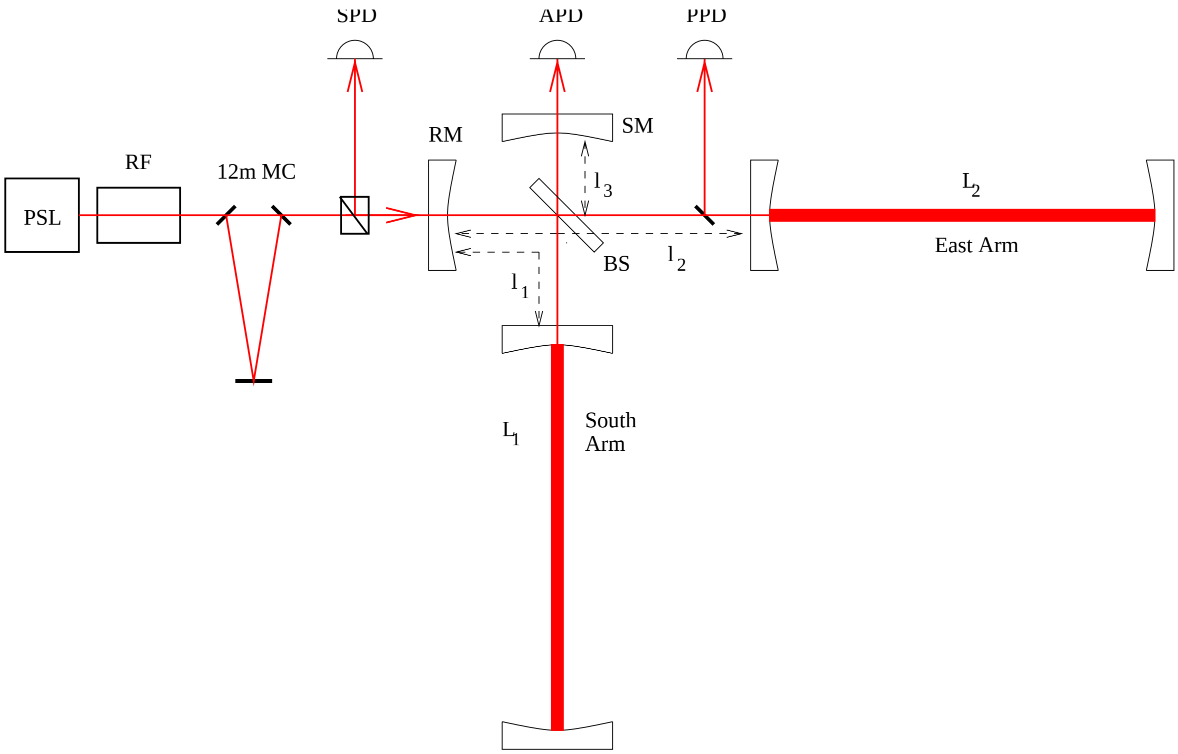
40m INFRASTRUCTURE UPGRADE

- LIGO-like upgrade, during next 1-2 years:
  - building modifications, control room, electrical
  - EPICS-based vacuum control system
  - LIGO-I PSL
  - fixed-spacer (1m) 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 to be built)
  - 7th suspended optic (SM)
  - control scheme for all optics
  - strawman: frontal mod with M-Z IFO
- Ready to prototype an RSE scheme by 2002.

40m upgrade

- Big outstanding questions:
  - Bake out entire vacuum envelope?
  - replace viton with damped metal springs in the passive seismic stacks?
  - replace existing seismic stacks with LIGO-II prototypes?
- Work closely with RSE and multiple pendula development at Glasgow and elsewhere
- 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).

Resonant Sideband Extraction

- Signal mirror in dark port
  decouples carrier storage time τ_c in arm cavity
  (maximize stored power $P \sim \tau_c$, $h_{DC} \sim 1/\sqrt{P}$)
  from signal storage time τ_s in arm cavity
  (tune F-P pole $f_s = 1/\tau_s$ to optimize $h(f)$)

- For fixed losses, $P = P_{laser} G(ARM) G(PRC)$;
  $R(ITM)$ controls the ratio $G(ARM)/G(PRC)$

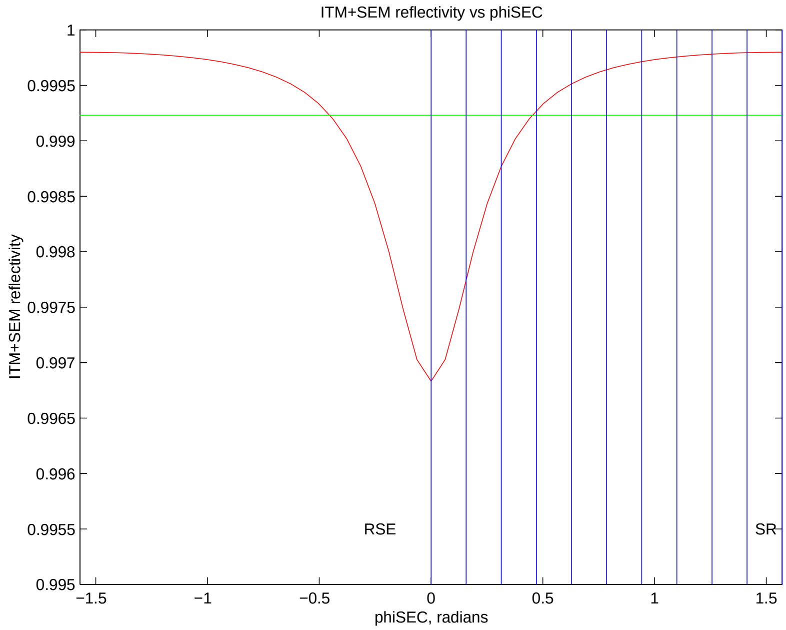
- Maximize ARM carrier gain $G(ARM)$,
  minimize PRC carrier gain $G(PRC)$,
  to minimize beam-heating effects in BS, ITMs.
  In absence of RSE, this leads to small $f_s = 1/\tau_s$

- RSE in broadband configuration permits
  low $G(PRC)$ characteristic of a narrow-band IFO,
  while retaining the shot-noise performance of a
  broader-band LIGO IFO.

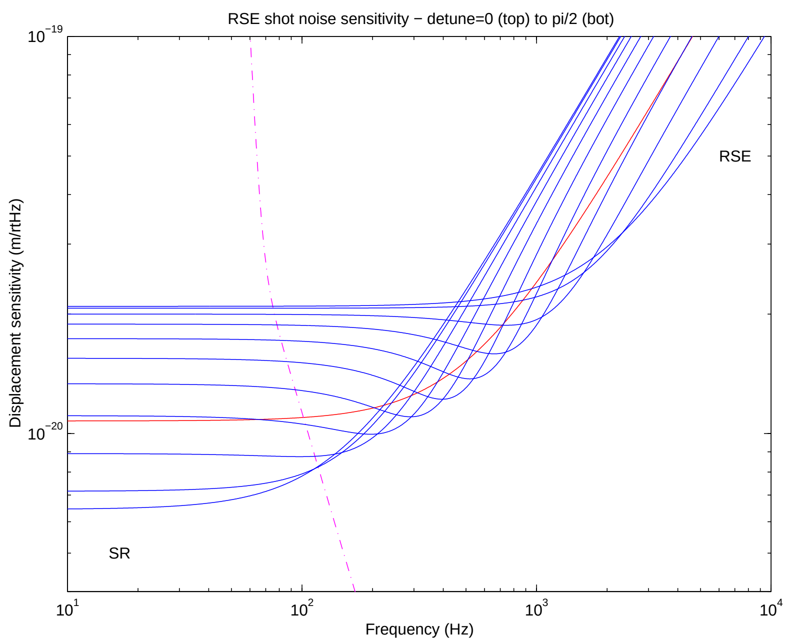
- Optimal sensitivity in the presence of thermal noise
  will likely require a *tuned* RSE configuration,
  with a dip "hugging" the thermal noise curve

RSE Transmission and shot noise

Coupled-cavity transmission:

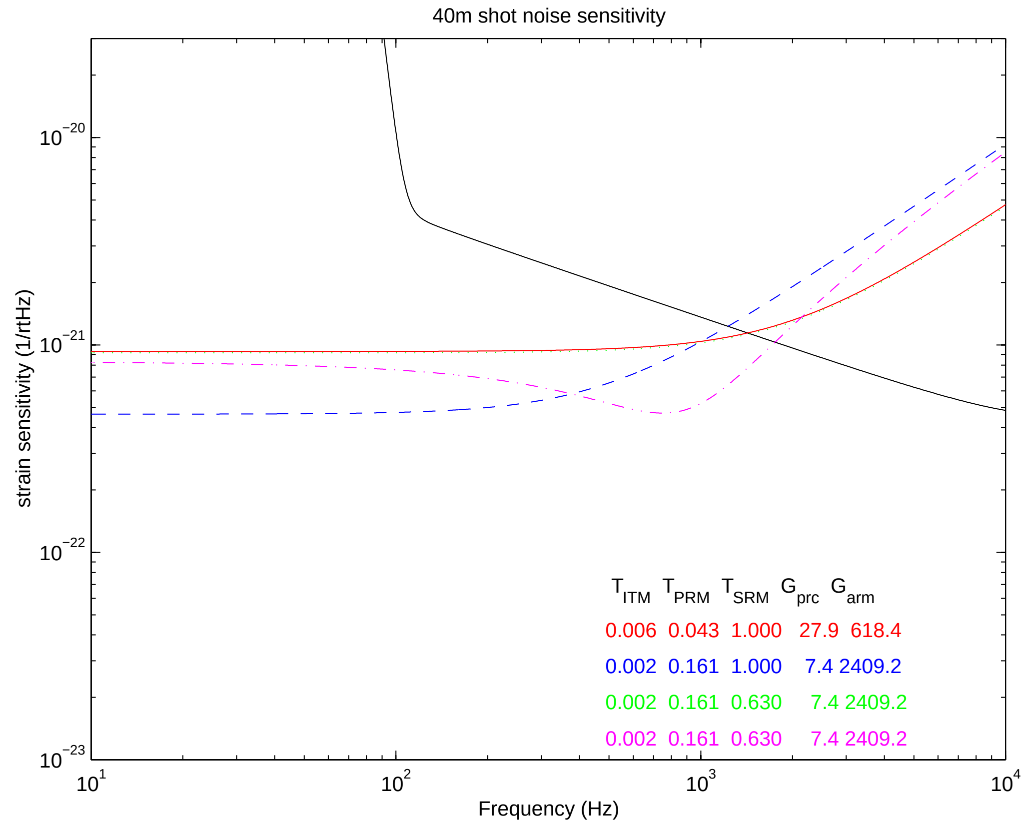


Shot noise curves for different tunings:



red: no SM; high $G(ARM)$, low $G(PRC)$

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

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

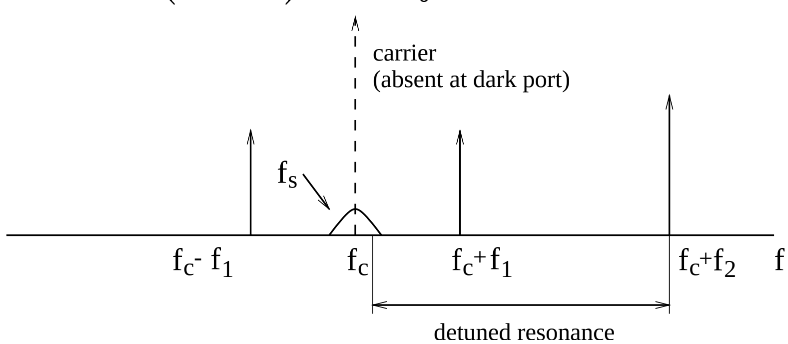
SRC tune $\phi_{cs} = 0.63$ rad

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

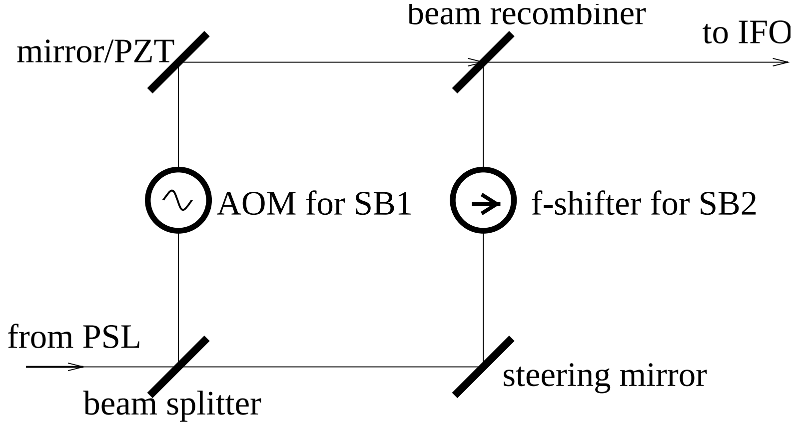
$h_{shot}(2185Hz) = 1.3 \times 10^{-21}/\sqrt{P_l}$

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_-

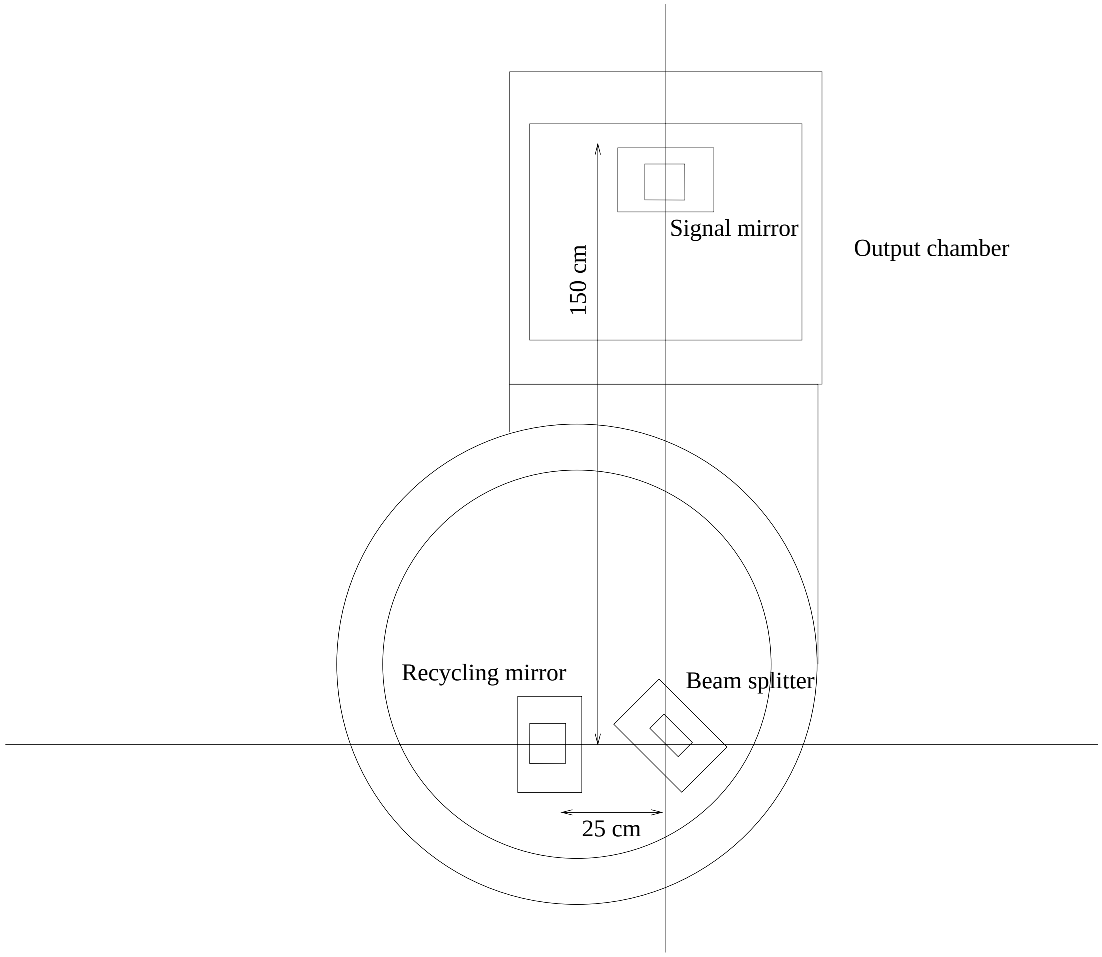
TWIDDLE and E2E models in progress!

Tunes, frequencies, cavity lengths

- SRC carrier tune: $\nu_{cs} \equiv mod(2 f_c l_s / c) = 0.1$
  (chosen to hug thermal noise curve)
  (in LIGO, chosen to optimize inspiral sensitivity)
- PRC cavity length: $l_+ \approx 229.0$ cm
  (fixed by 40m vac envelope)
- SB1 frequency: $f_1 = 32.729$ MHz $(= c/(4 l_+))$
- SB2 frequency: $f_2 = 3 f_1 = 98.188$ MHz
- SRC cavity length: $l_s = 366.4$ cm $\left(= \left(\frac{5}{3} - \frac{2}{3}\nu_{cs}\right) l_+\right)$
- Schnupp asymmetry and all cavity lengths remain to be optimized!

Cavity	arms	PRC	SRC
carrier	$\nu_{ca} = 0.00$	$\nu_{cp} = 0.00$	$\nu_{cs} = 0.10$
SB1	$\nu_{1a} = 8.35$	$\nu_{1p} = 0.50$	$\nu_{1s} = 0.80$
SB2	$\nu_{2a} = 25.05$	$\nu_{2p} = 1.50$	$\nu_{2s} = 2.40$

Will it fit?



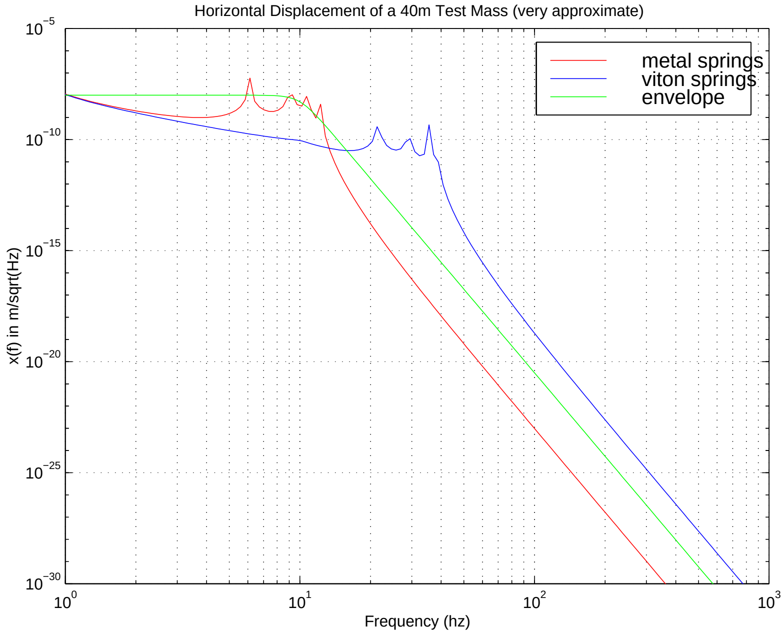
For broadband operation ($\phi_{cs} = 0$, worst case),
need $\sim$ 178 cm. Have only $\sim$ 150 cm!
May only be able to operate with $\phi_{cs} \gtrsim 0.5$ rad!
More careful optimizations and drawings are in the works.

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
- fixed-spacer mode cleaner design
- Twiddle and E2E models
- FFT modeling (so far, perfect optics only)

Seismic noise

Here is the expected contribution to the horizontal displacement, x_{rms}(f), from seismic motion.



Damped metal springs move seismic wall (100→40) Hz; but larger $x(10Hz)$, x_{rms}, v_{rms} $\Rightarrow$ control problem?

$$x_{green} \approx \frac{1 \times 10^{-8} \quad \text{meters}}{1 + (f/10)^{12.5}}$$

$$h_{strain} = \frac{2}{L_{arm}} x_{rms}(f)$$

Vacuum Contamination

- 40m has endured anomalous optical losses (green) (Expected < 50 ppm; saw ~ 200 ppm)
- Is this due to the unbaked vacuum envelope?
- Do the viton springs outgas flourocarbons which degrade high-R optics?
- Are these problems reduced in moving to IR?
- Are they exacerbated in the high-F cavities of the upgrade?
- Overall 40m vacuum is good ($\sim$ few $\times 10^{-6}$ torr); hydro- and flourocarbons at $\sim$ few $\times 10^{-11}$; expect improvements with upgraded system (IP's)
- Contamination test cavity (Camp et al) sees no evidence of degradation with IR
- Bake-out, stack rebuild is a BIG job!

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? Rebuild 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 rebuild the seismic stacks,
  replacing stiff-but-well-damped viton
  (contaminating the vacuum at a low level?)
  with soft but-poorly-damped metal springs?
- Should we consider employing
  advanced (scaled down) SEI systems?
- should we consider prototyping advanced SUS systems
  (multiple pendula, electrostatic control)?
- Is the "simple" control scheme developed by Mason
  adequate for LIGO-II?
- How can we implement it? M-Z? $f_{RF2} = 100$ MHz?
- Modulation in vacuum or air? Before/after MC?
- where will we get the physicists and eng. support?