40m Laboratory Progress Report

LSC meeting at LIGO Hanford Observatory

Alan Weinstein, Caltech

LIGO-G040325-00-R

40m Team

On the payroll: Ben Abbott, Osamu Miyakawa, Bob Taylor, Steve Vass, Alan Weinstein

Grad students: Lisa Goggin, Rob Ward

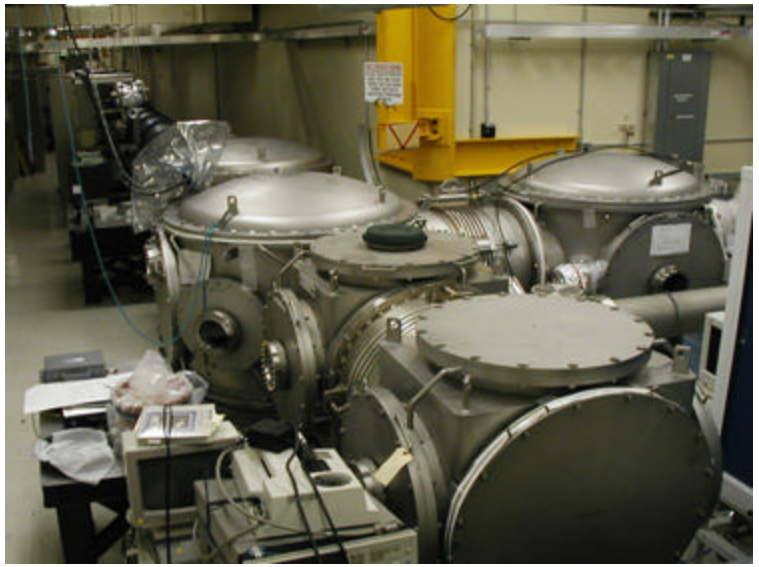
LIGO engineering support: Jay Heefner, Rolf Bork, Alex Ivanov, Flavio Nocera, Michael Smith, Lisa Bogue, many others

Visitors: Seiji Kawamura, Fumiko Kawazoe, Shihori Sakata, Bryan Barr, Sascha Schediwy, Kentaro Somiya, Rana Adhikari (Hartmut Grote of GEO arrives Oct 1)

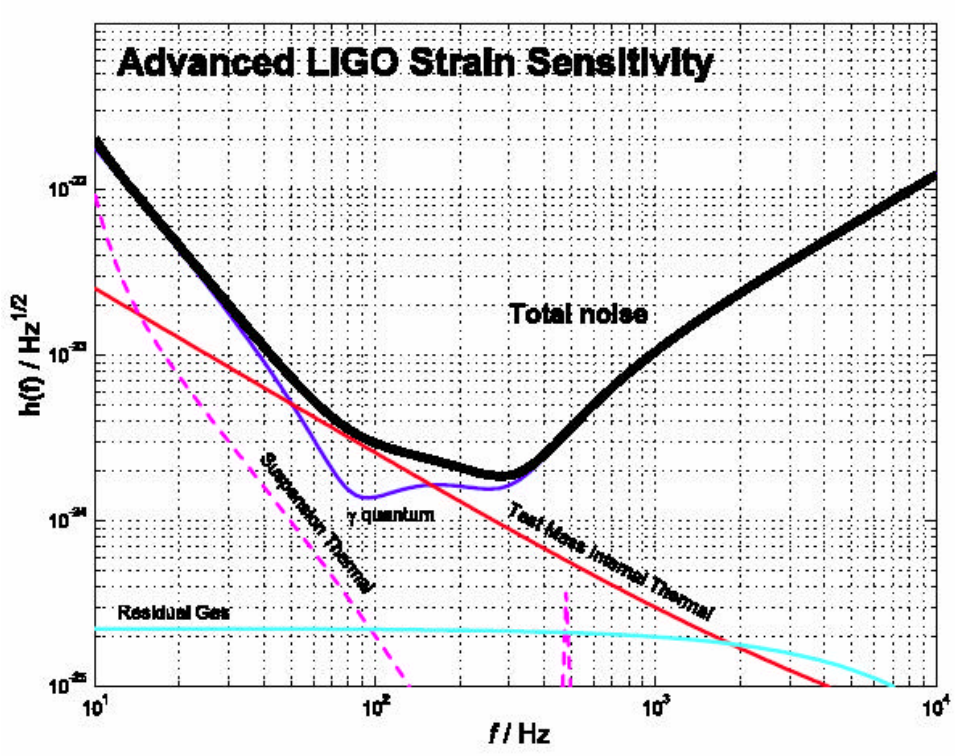
Objectives

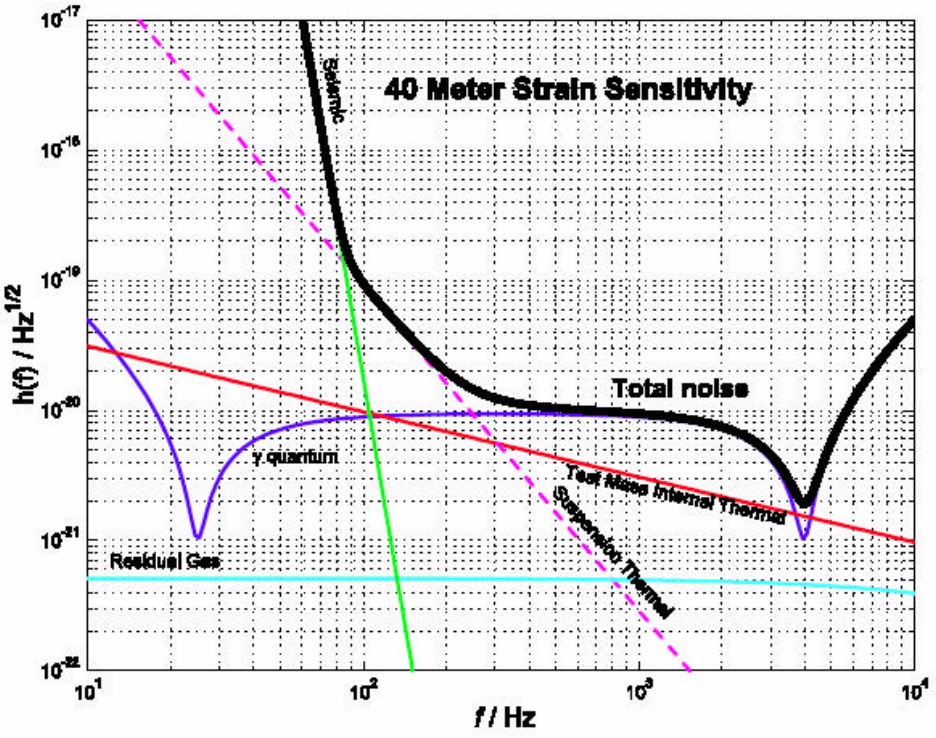
- Develop **lock acquisition procedure** of detuned RSE dual-recycled FPMI interferometer, as close as possible to Advanced LIGO design
- Characterize noise mechanisms
- Verify resonant sideband extraction, optical spring effects
- Develop DC readout scheme
- Extrapolate to AdLIGO via simulation
- etc.

for Advanced LIGO, LCGT,
and other future GW detectors



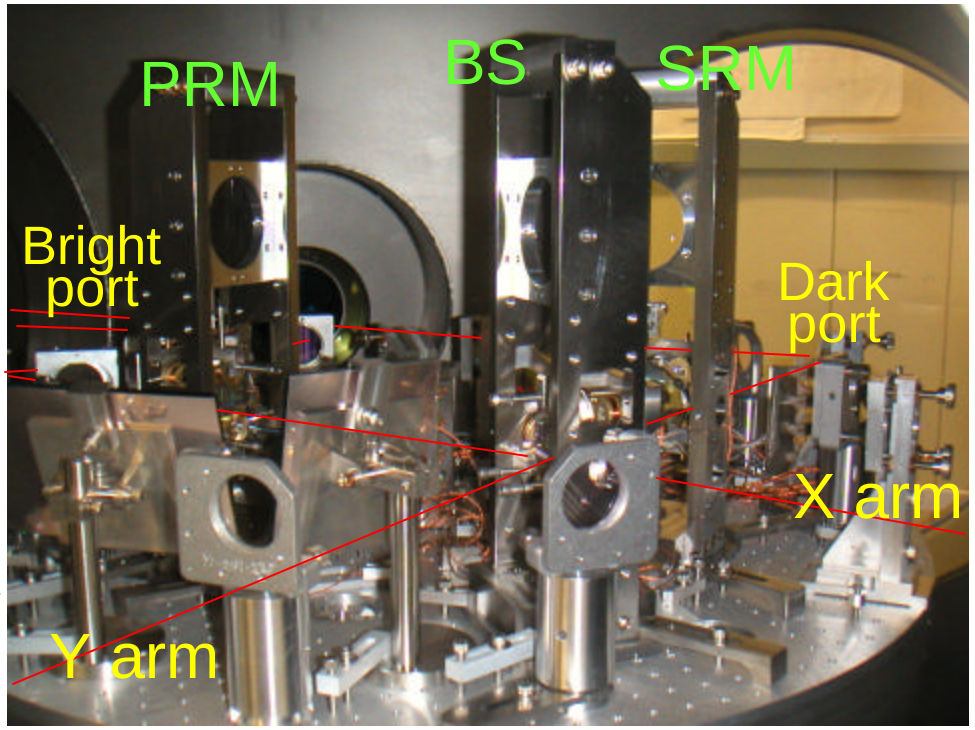
Target Sensitivity of Advanced LIGO and 40m

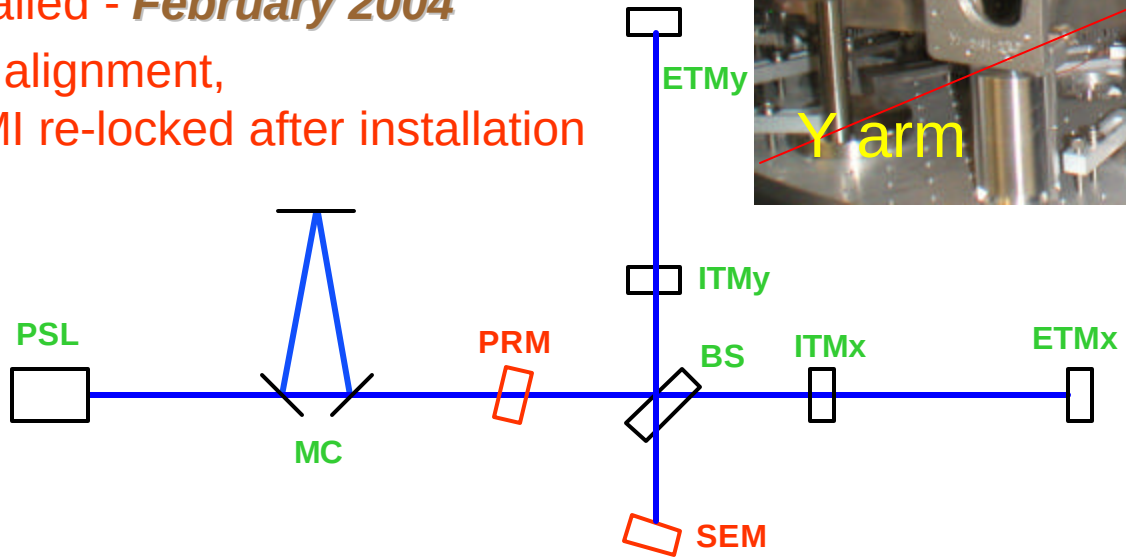


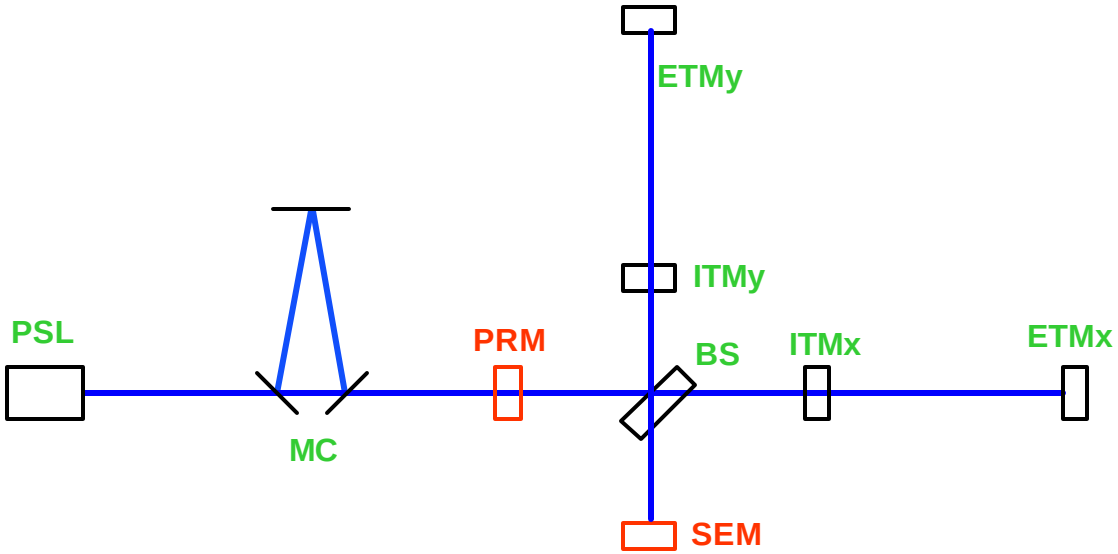


Important Milestones in last year

- Four TMs and BS: installed - ***September, 2003***
- FP Michelson locked – ***November 2003***
- Displacement spectrum obtained - ***November ~ December 2003***
- Power Recycling Mirror (PRM) , Signal Extraction Mirror (SRM) installed - ***February 2004***
- Full alignment,
  FPMI re-locked after installation



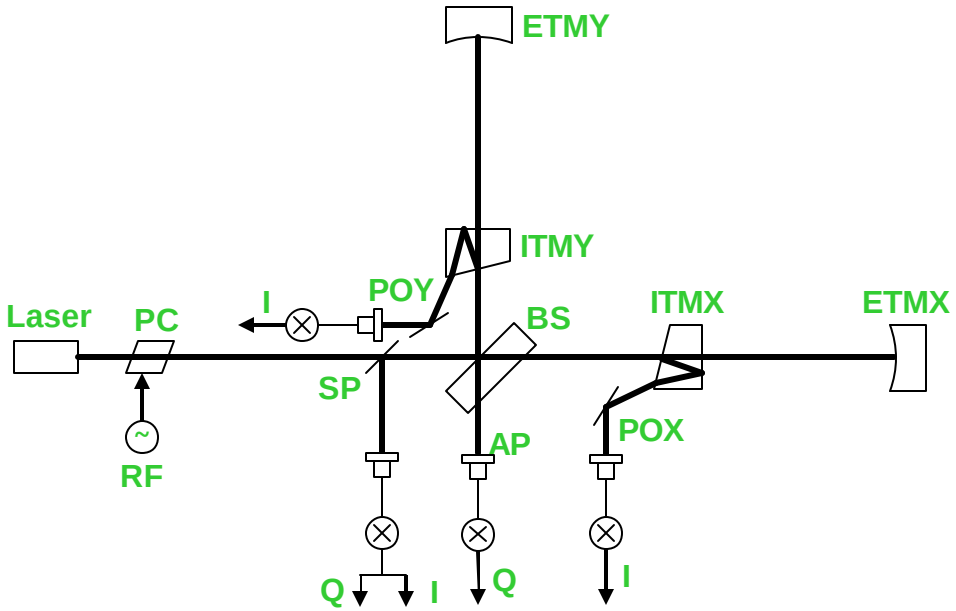



ETMy
ITMy
PSL
PRM
BS
ITMx
ETMx
MC
SEM

Lock Acquisition of FP Michelson

November 2003

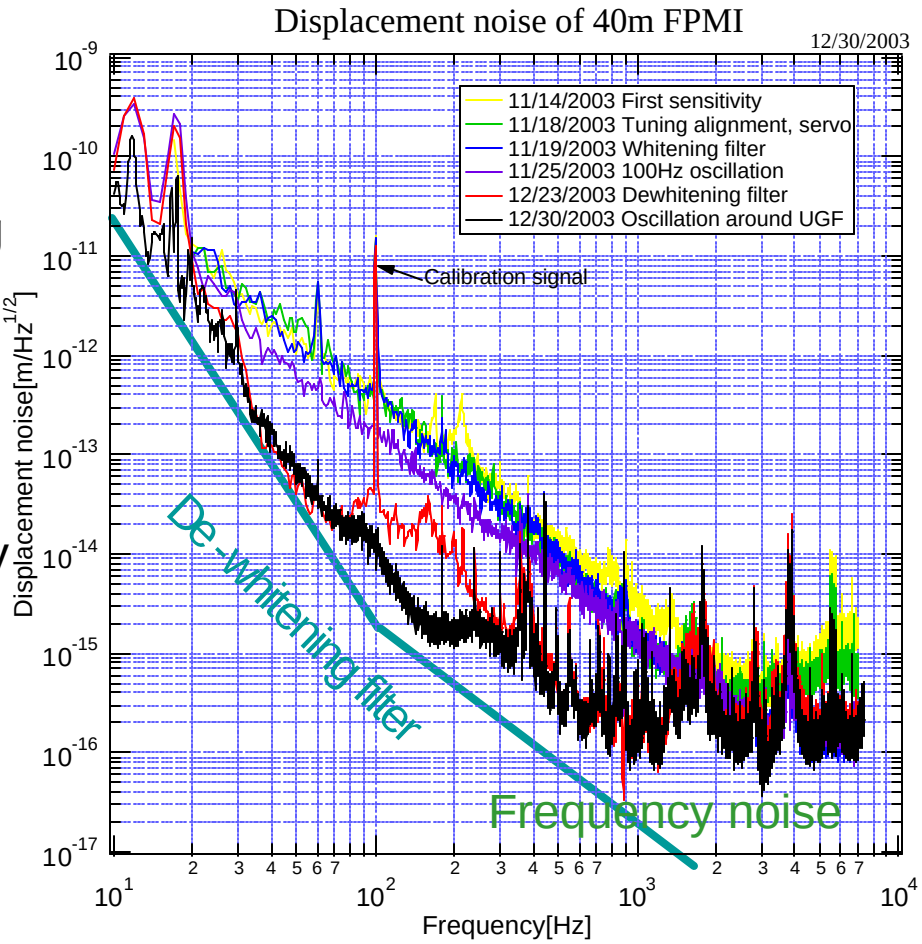
- FP Michelson locked
- Arms locked independently, and switched to common/differential servo
- All locking and transitions handled by digital LSC system.
- Autolock scripts being refined.
- Arm finesse ~ 1200
- Seismic motion ~ 10 - 100 times noisier than LIGO site
- UGF ~ 300Hz (limited by A/D and D/A speed)



Spectrum of FP Michelson

November ~ December 2003

- Displacement spectrum obtained
- With all the whitening/de-whitening filters (2 of 4 orders) ON
- No feedback to laser frequency
- 2 months noise hunting
- Noise is limited by electronic noise of de-whitening filter and frequency noise.



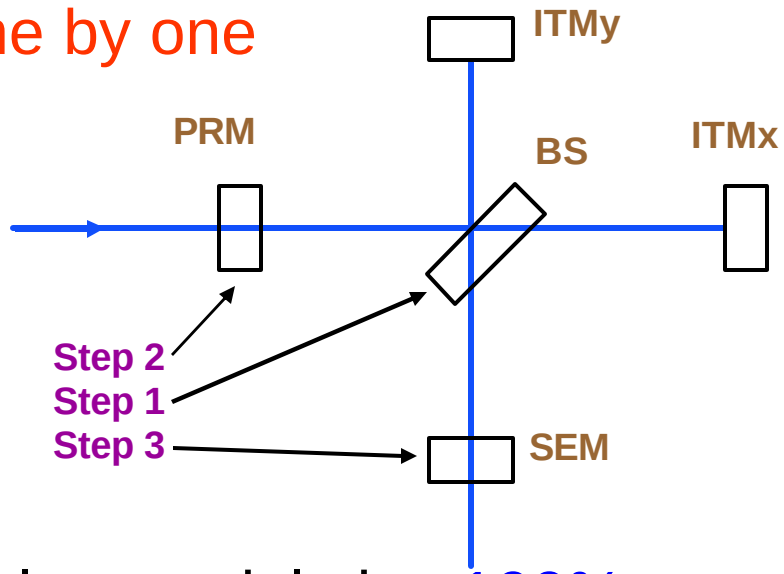
Work on lock acquisition and control of dual-recycled IFO since March

- Development of **lock acquisition schemes** by Seiji and Osamu
- *Most* of **LSC hardware** assembled and commissioned
- Complete installation of **RF distribution** for LSC/ASC (5 RF freq's)
- **LSC software** completely rewritten for control of dual-recycled IFO:
  - » Handles more RF and DC signals
  - » Larger input and output matrices
  - » More general: no hard-coding of, eg, "AS_I"
  - » assemble double-demod signals in software
  - » digital dither-locking signals
  - » Much flexibility in dynamically forming the input matrix
  - » many other clean-up improvements
- **Locking of FPMI with digital LSC system** (misaligned PRM, SRM), measurement of displacement noise
- **Dither-locking of MICH** @ 1200 Hz with digital LSC system (intermediate step for robust locking of DRMI)

Lock Acquisition of Central Part

Ideal Procedure: Lock one by one

Step 1: Lock *l*- robustly
Step 2: Lock l_+ robustly
Step 3: Lock l_s



1. l-: dither, @ $\frac{S_{AP}P_{SP} - S_{SP}P_{AP}}{P_{SP}^{\ 2}}$ with low modulation:100%
2. l+ : double demodulation 88,180 deg. @ SP :100%
3. ls : double demodulation 164,12 deg. @ PO :100%

Switch to design control topology, open shutter, lock arms

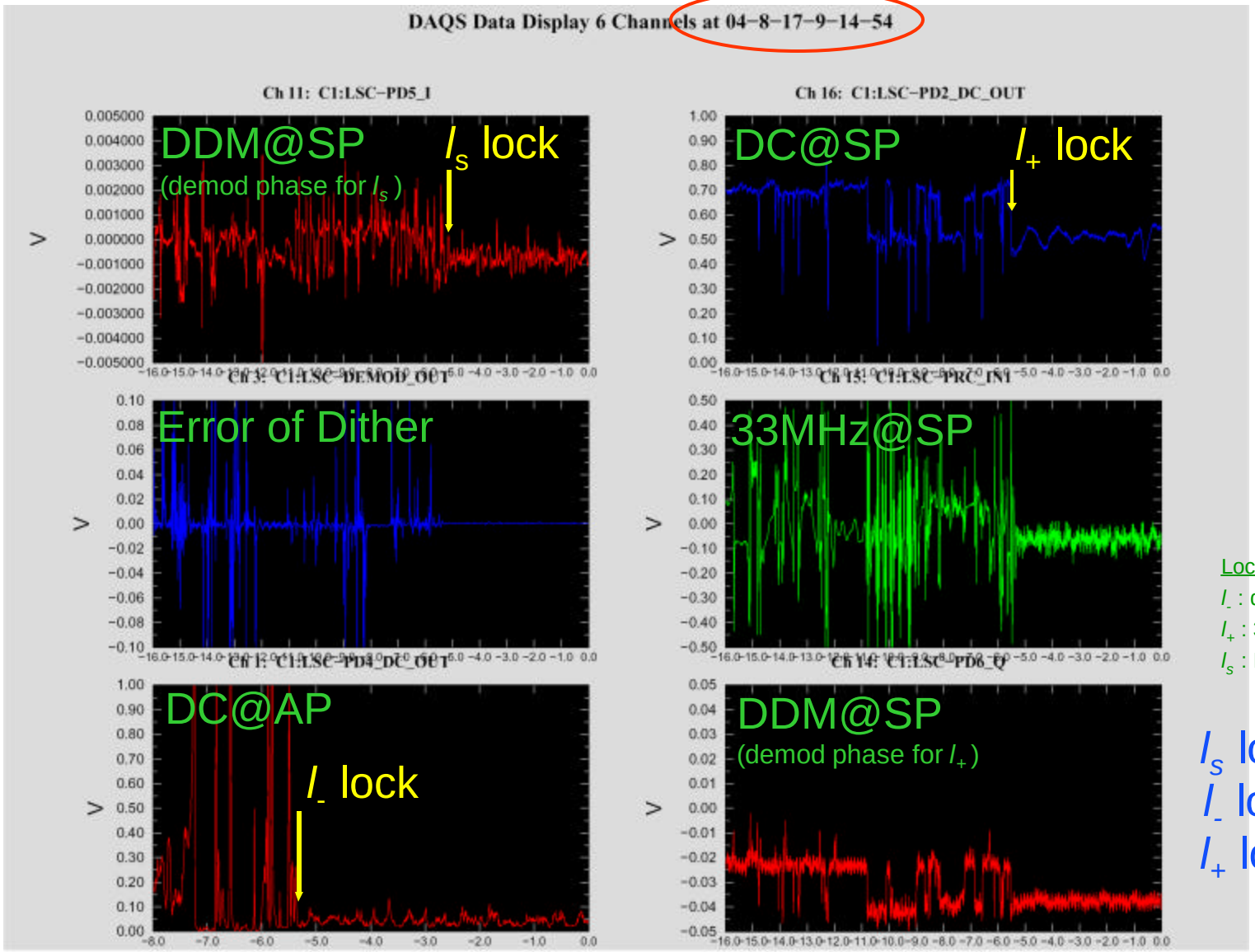
Work on lock acquisition and control of dual-recycled IFO since March

- Commissioning of **double-demodulation** at SP photodetector
- Attempt to form DDM signal and adjust demod phases → discovery that **sidebands on sidebands** were missing from Finesse and Twiddle models (May 2004)
- Analysis of sb-on-sb problem, and decision to construct **Mach Zehnder** (May/June 2004)
- **Construction and commissioning of MZ, optimization of servo** (June/July 2004)
- Measurement of **MZ displacement noise, intensity noise, frequency noise** (July/August 2004)
- **Lock MC to MZ-transmitted beam**. Re-align entire IFO (Aug 2004)
- **Lock FP arms to MC-transmitted beam**. (Aug 2004)
- **Recover dither-lock of MICH, using PO port. Even with PRM and SRM aligned and swinging freely**. (Aug 2004)
- Commission **DDM signal extraction at SP** (Aug 2004)
- Study of **phase noise introduced by MZ** → L- signal

Locking dual-recycled IFO

- **Lock central part of IFO** : l_- (MICH) , l_+ (PRC), l_s (SEC)
  (early this morning, August 17, 2004)
- Not at final configuration (DDM at AP and PO not yet commissioned; arms blocked; more LSC coding to be done…)
- Lock now: Control later:
- l_- : dither @ 1200 Hz $\rightarrow$ DDM@AP
- l_+ : 33@SP $\rightarrow$ DDM@SP
- l_s : DDM@SP $\rightarrow$ DDM@PO
- Carrier resonant in PRC instead of 33MHz sidebands
  (carrier should be ~anti-resonant until arms are locked).
- Lock is pretty stable (more than 10 minutes).
- Achieved DRMI lock more than 10times. All locks were stable.
- +166MHz decreased on the Tropel at SP during the lock, as expected if +166 is being transmitted to AP (no Tropel at AP at the moment).

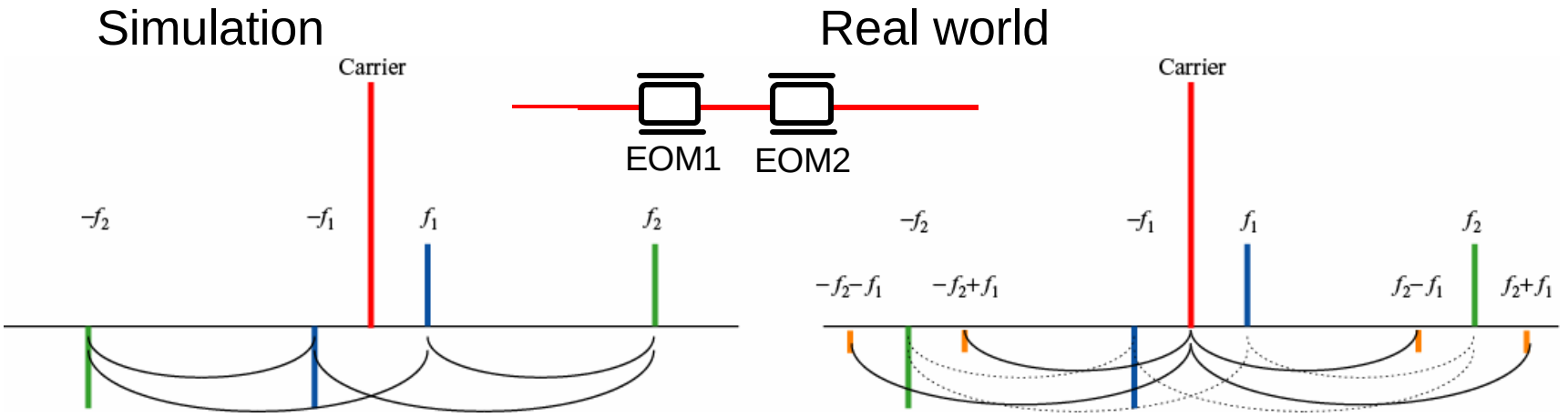
First lock of Dual recycled Michelson



Lock now:	Control later:
l_- : dither @AP	→ DDM@AP
l_+ : 33@SP	→ DDM@SP
l_s : DDM@SP	→ DDM@PO

l_s lock at -5.2 sec
l_- lock at -5.3 sec
l_+ lock at -5.6 sec

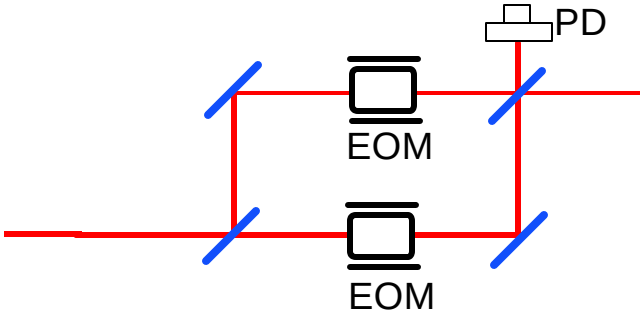
Sidebands of sidebands



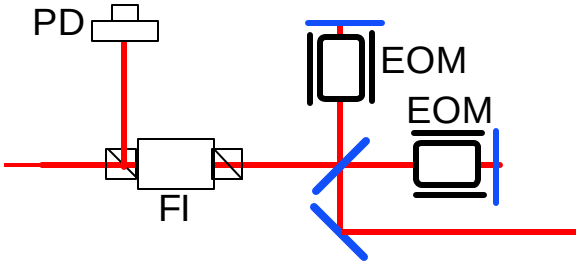
- Desire to control short degrees of freedom (MICH, PRC, SRC) using beats between RF sidebands only ($f_1 \pm f_2$), no carrier, to be immune to large signals from arm cavities
- Application of f_1 and f_2 using serial EOMs produces sidebands on sidebands, at ($f_1 \pm f_2$), so that beats appear with carrier, corrupting signals for short dof's.
- In our modeling, we simply forgot this fact (even though it was well known to people prototyping RSE table-top interferometers)
- After considering several solutions, we decided to go with parallel EOMS via Mach-Zehnder interferometer (as was done by several tabletop prototypers).
- MZ introduces various kinds of noise. We think that AdLIGO can handle it!

To eliminate sidebands of sidebands

- Mach Zehnder interferometer
  - » 1/2 modulation index (1/4 sideband power)
  - » Need one more control
  - » Amplitude noise, frequency noise

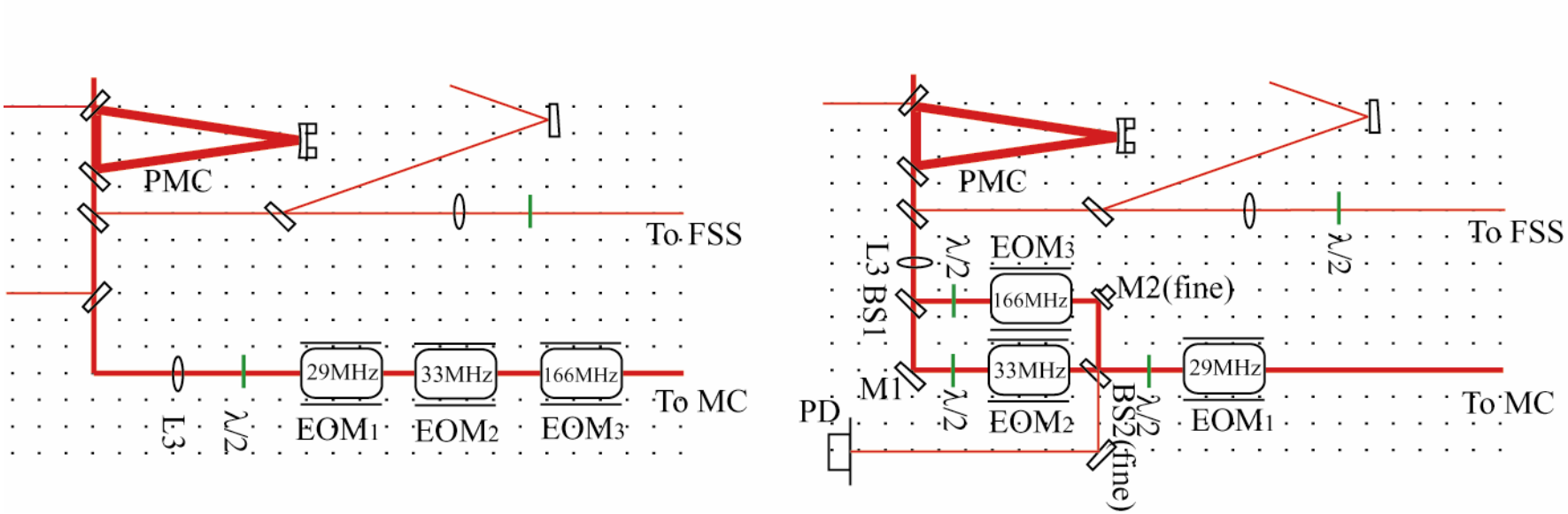


- Michelson interferometer
  - » Same modulation index as series EOMs
  - » Faraday-isolator
  - » Need one more control
  - » Amplitude noise, frequency noise



- 2 more AOM to kill 133MHz and 199MHz
  - » 1/2 carrier power
  - » Need to adjust phase and amplitude
- Using a broad band EOM to kill 133MHz and 199MHz
  - » Not easy to kill amplitude modulation

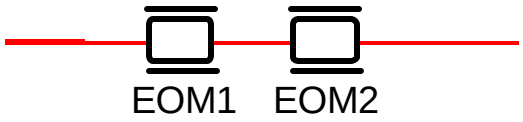
Mach-Zehnder on 40m PSL



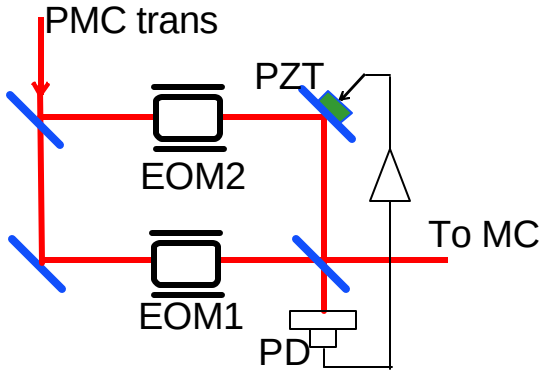
- Control
  - » Originally, using internal modulation with 33MHz to lock MZ
  - » Might need to turn down 33, 166 MHz during lock acquisition procedure; don't want to lose MZ lock
  - » Instead, put 29 MHz EOM (used for MC lock) into MZ east arm, and lock with that → now using 29MHz!
  - » MUCH work on servo optimization, autolocking, etc. All works well!

Mach-Zehnder on 40m PSL to eliminate sidebands of sidebands

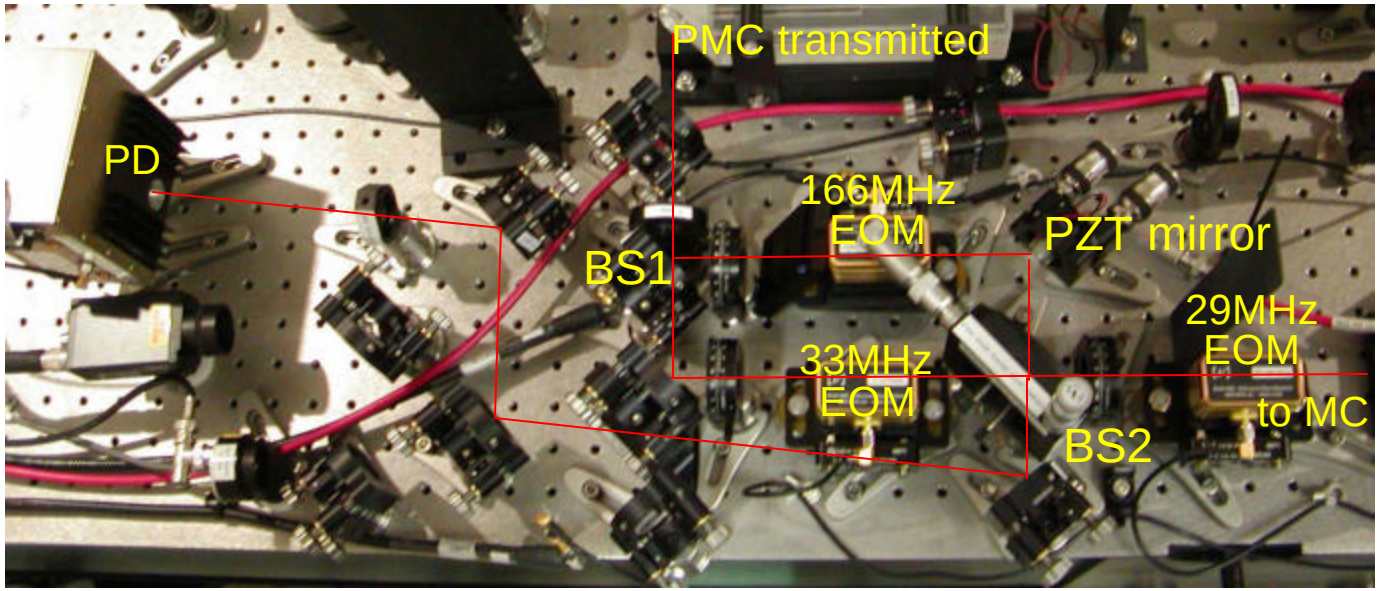
Series EOMs
with sidebands of sidebands



Mach-Zehnder interferometer
no sidebands of sidebands from beginning

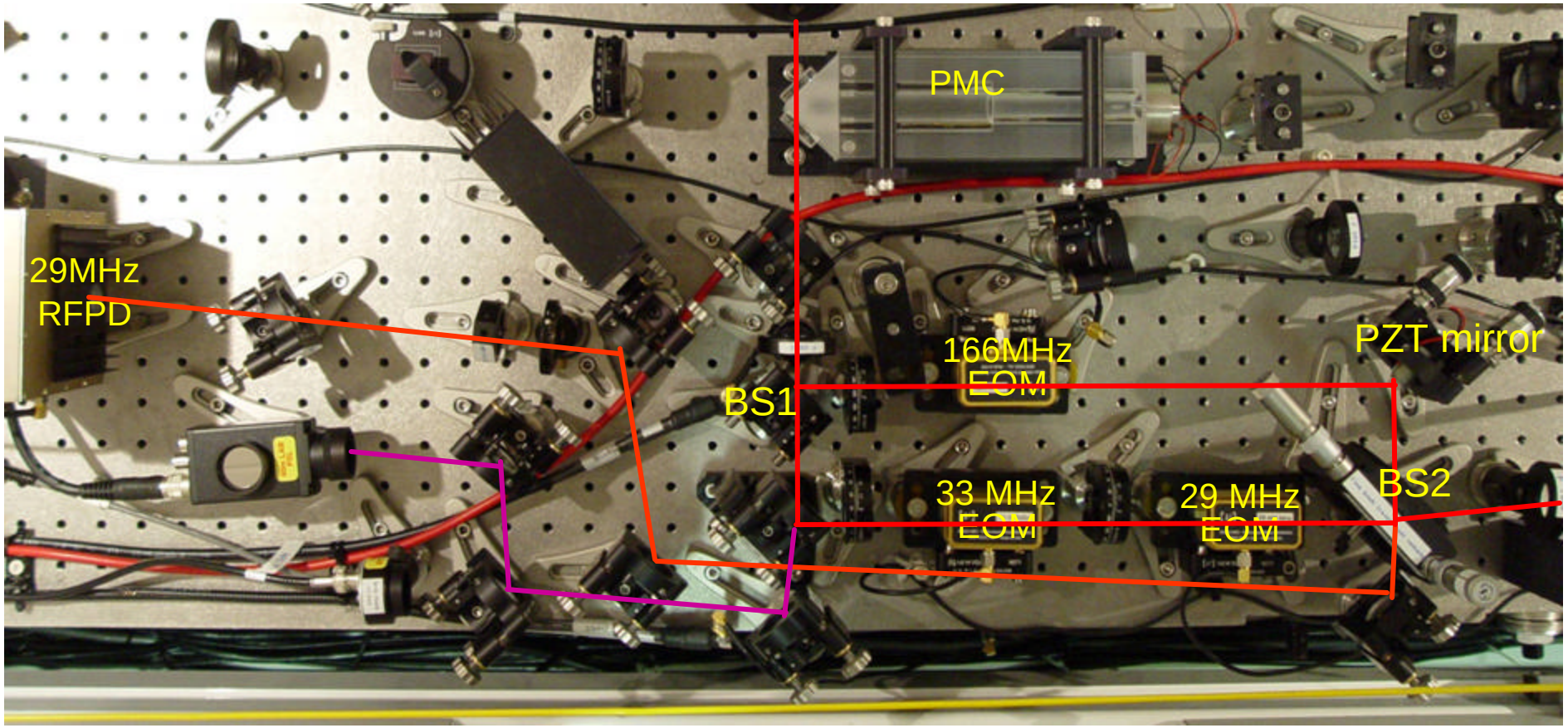


Using 33 Mhz to lock:



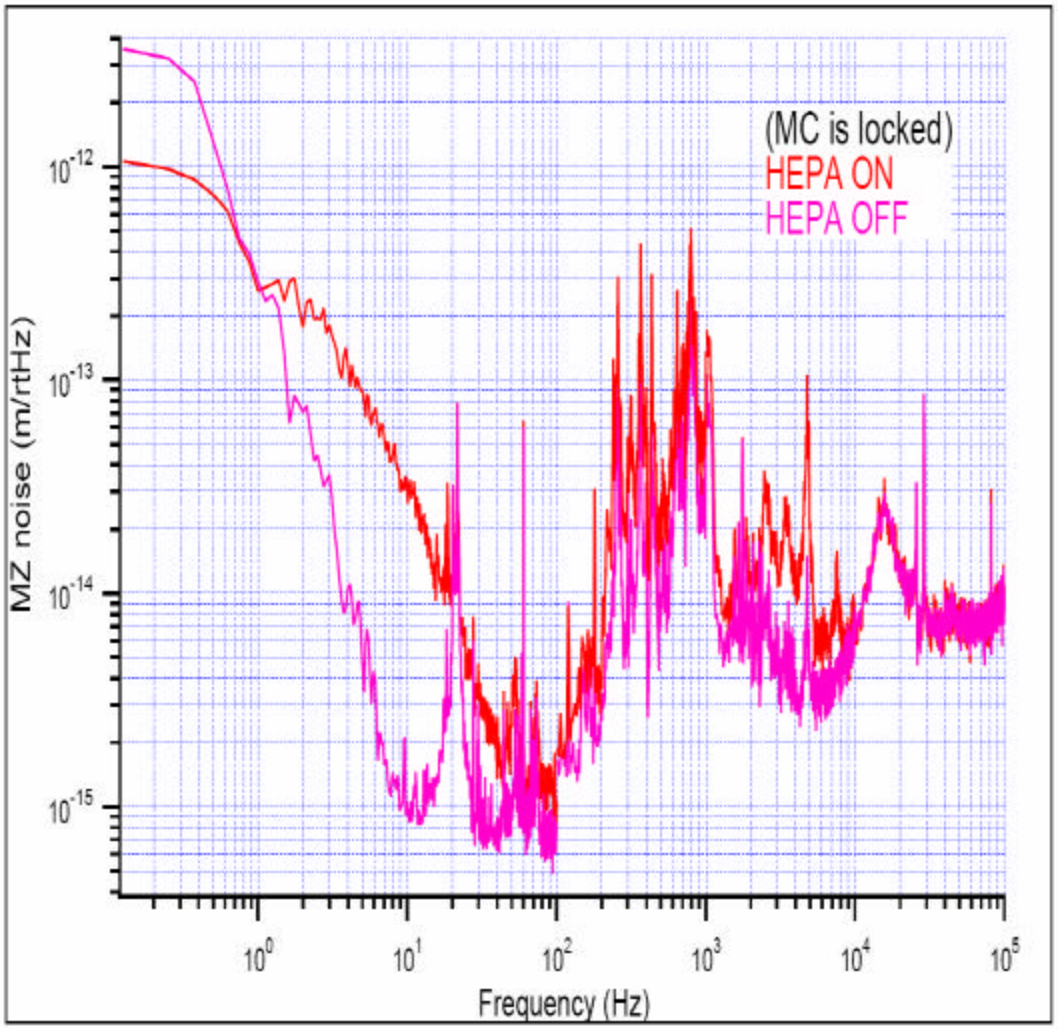
Mach-Zehnder on 40m PSL

Using 29 Mhz to lock:



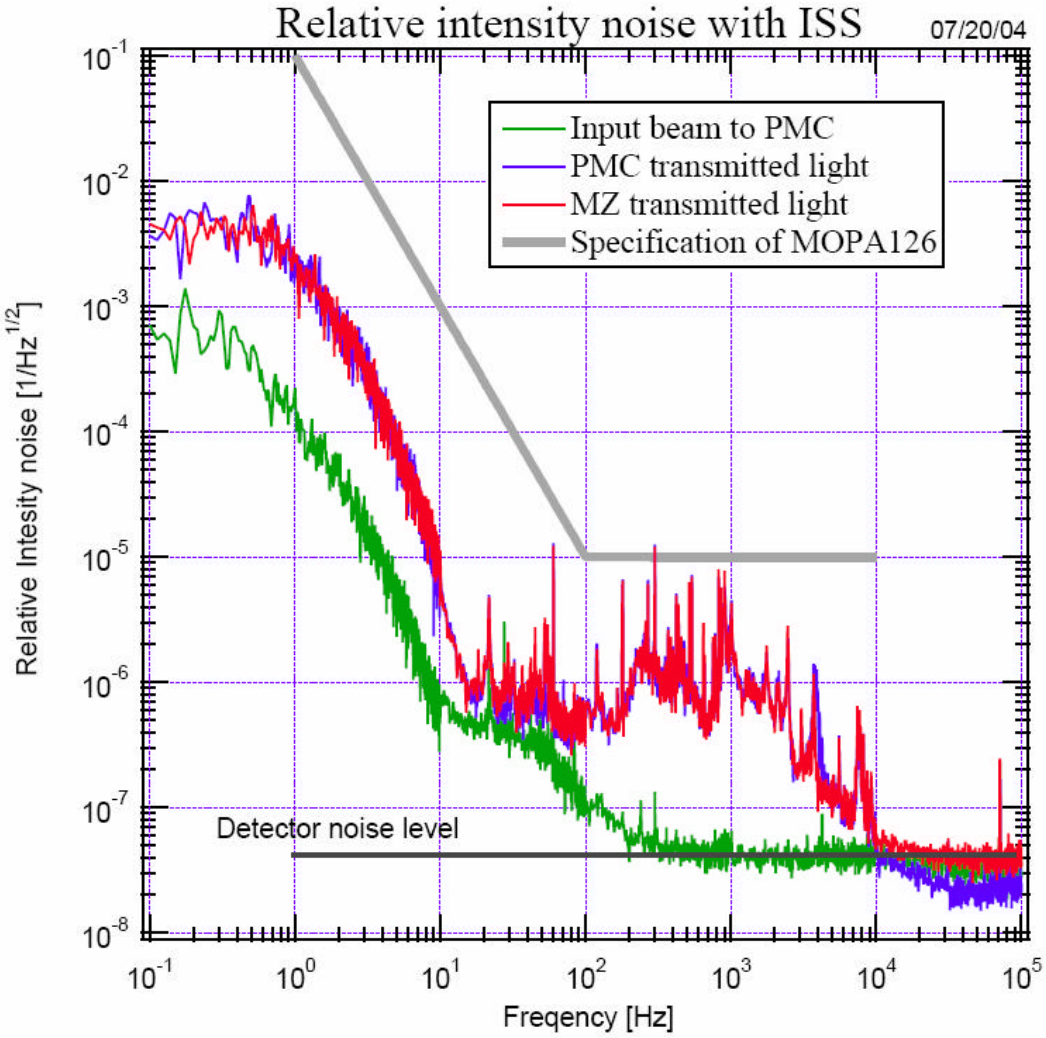
MZ in-loop displacement noise

- Calibrated by sweeping DC offset slider from bright to dark fringe.
- Taken after a good deal of alignment and MZ servo optimization, but…
- There has been some further optimization of the MZ servo since then.
- PSL enclosure HEPA filters ON: lots of acoustic noise.
- New measurements of displacement, intensity, frequency noise in progress.



MZ Intensity noise

- MZ adds no noticable additional intensity noise after PMC.
- Same conclusion, with ISS turned off.
- We have subsequently move the ISS pickoff from before the PMC to after the PMC & MZ.
- New measurements in progress.



MZ eliminates sidebands on sidebands

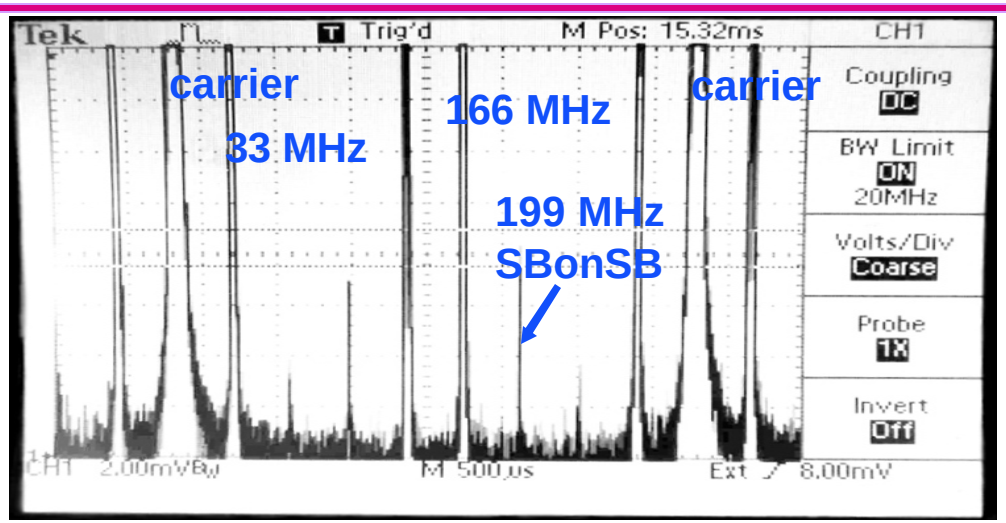
And lo and behold:

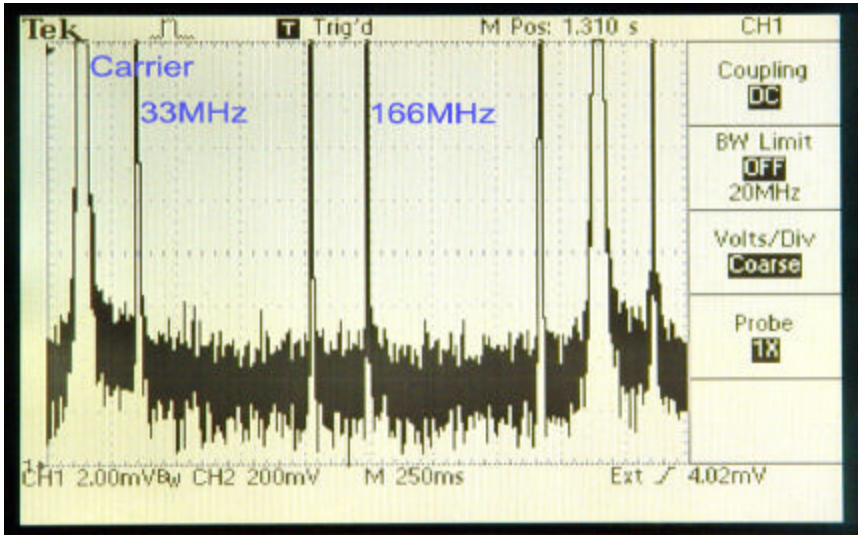
No sidebands on sidebands!

MCT light, series EOMs

parallel EOMs in MZ ifo

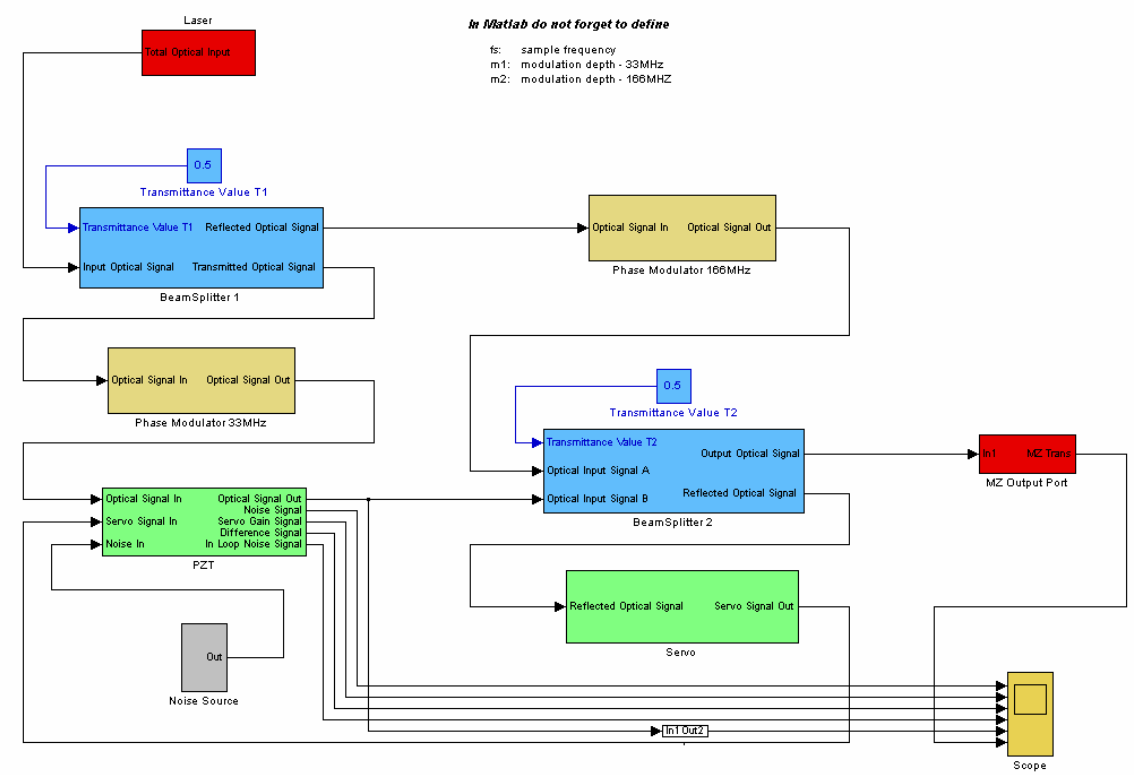
(hard to directly compare because we can't turn the modulation depth up as high as we could before; but we can get up to $\Gamma = 0.25$ easily)



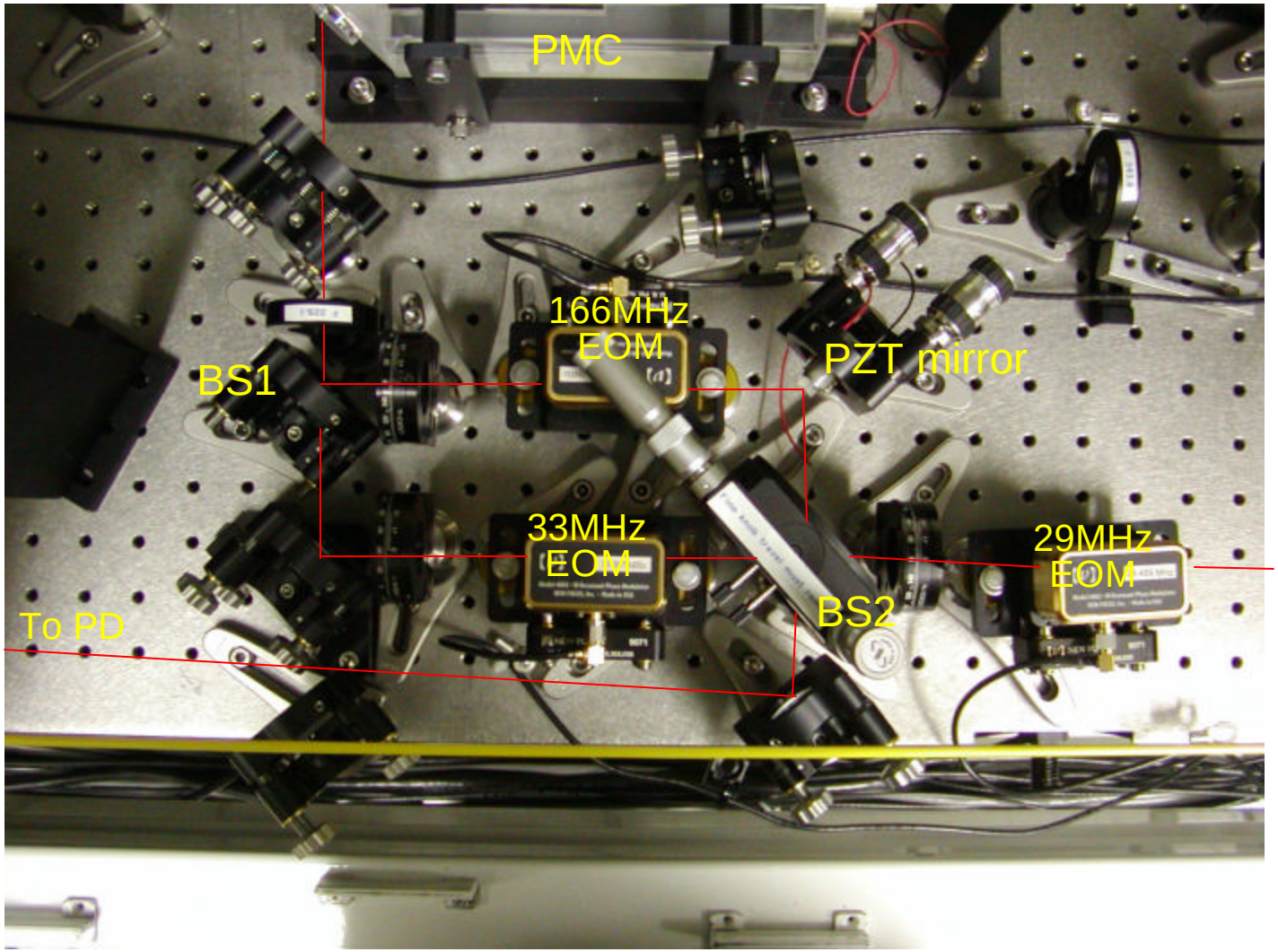


Modeling of Mach-Zehnder

- Sascha Schediwy, visiting from Perth, has developed a simulink model
- Monica Varvella, visiting from Orsay, has developed an e2e model



Mach-Zehnder on 40m PSL



More work since March (1)

- **MUCH work on PSL FSS and ISS**:
  - » Replaced dying NPRO. MUCH pain with misbehavior, heating, etc.
  - » Hunting down and fixing many sources of oscillation in FSS servo
  - » Complete re-alignment, mode-matching on entire PSL table
  - » Calibration for and measurement of PSL frequency noise
  - » Prototyping current and next generation of ISS servos
- **Complete installation of all beamlines**, commission and align QPDs, EOSs, RFPDs, cameras, cabling.
- **Complete re-alignment**, from PSL → MZ → MC → PZTs → IFO
- MUCH work on **MC length servo**. MC autolocks easily and robustly.

More work since March (2)

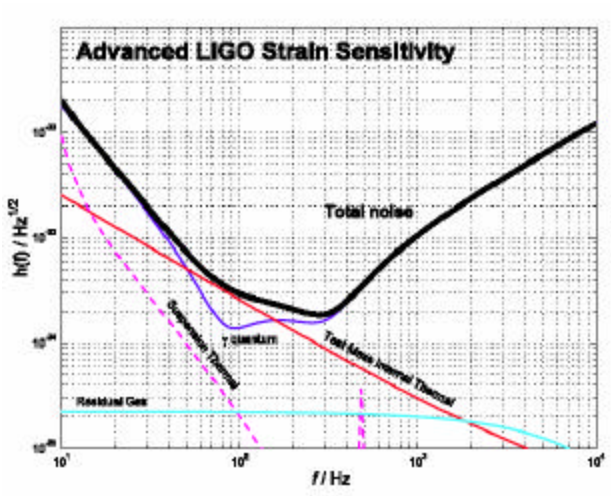
- **Digital suspension controllers** (work in progress)
  - » optimization of damping servo gains & filters
  - » diagonalization of input matrices
  - » diagonalizing output matrices, Pos2Pitch compensation filters
  - » oplev servo implementation and optimization
- Rana working to make our **computing environment, DAQ, EPICS**, etc as up-to-date as at the sites
  - » MUCH work on EPICS screens, databases, autoburt / saverestore, scripts, DAQ channels, etc.
- Upgrade of **safety procedures & documents**, lockout/tagout, fire alarms, training, etc.
- Repair of **STACIS seismic isolators** (in progress)
- Repair and refinement of **vacuum equipment & controls**

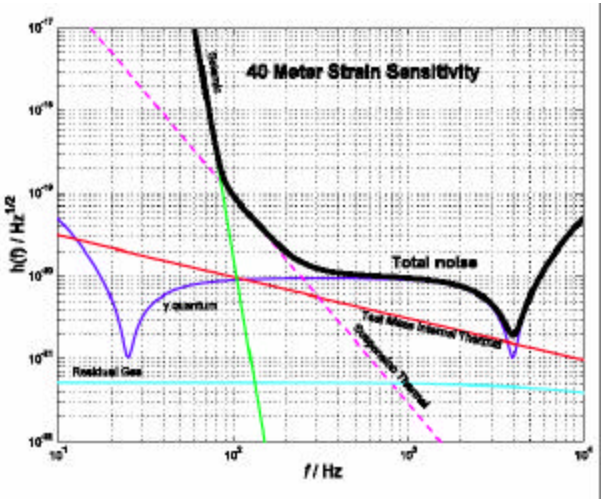
Plans for near future

- Continue march towards lock acquisition of DRFPMI
  - » Complete work on LSC photodetectors and electronics
  - » Optimize dither-locking of MICH
  - » Establish double-demod signals for PRC/SEC, and set demod phases
  - » Lock central part (MICH/PRC/SEC) and transfer to final control config
  - » Add arms to locked central part
  - » Switch smoothly to DARM/CARM
  - » Add common mode servo
  - » Automate smooth lock acquisition procedure

Once we acquire full lock

- Measure in-lock transfer functions.
- Verify RSE and optical spring
- Begin noise characterization
- Operate at a different SEC tune?
- Begin work towards DC detection
  - » output mode cleaner
  - » offset locking of arm
  - » DC photodetector
  - » noise characterization





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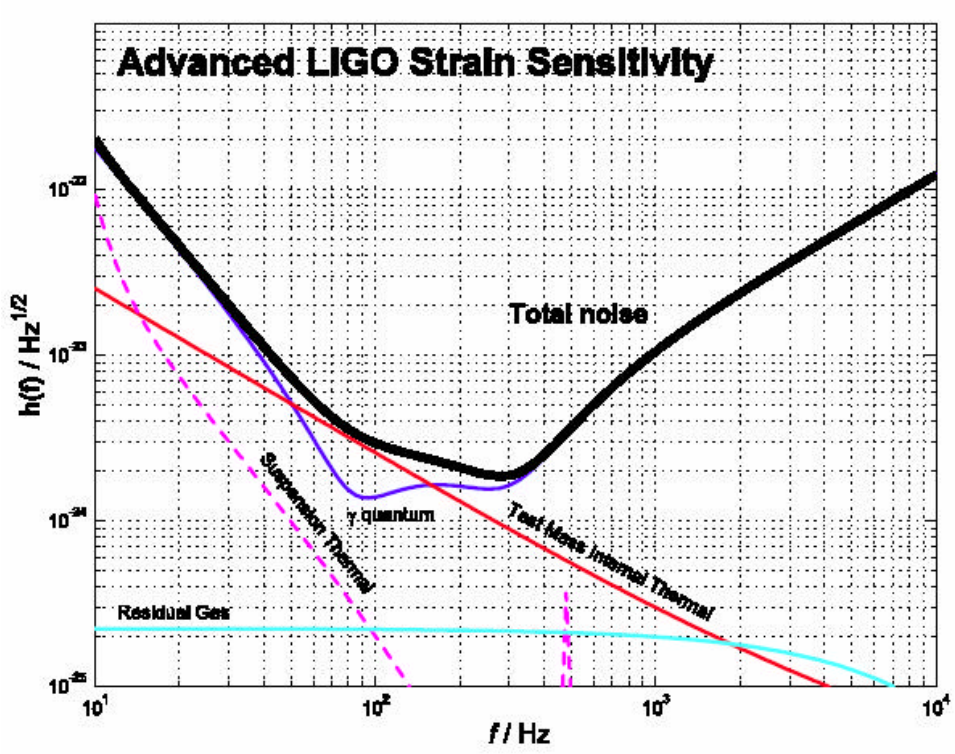

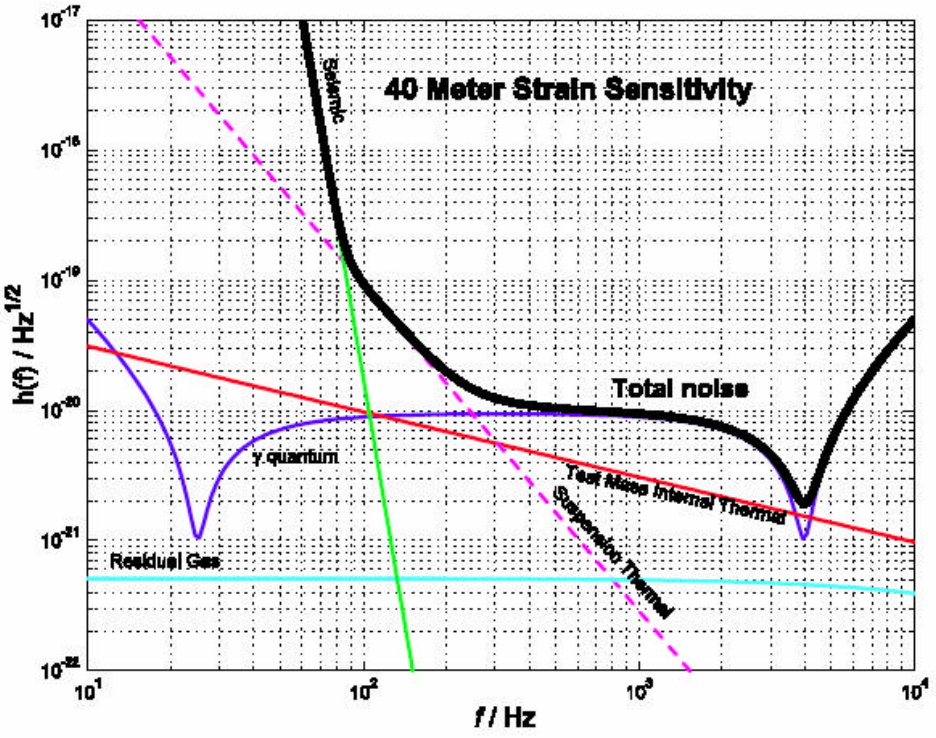

Further work on infrastructure (1)

- We desperately need to upgrade our **computers and controls software**!
- Complete optimization of **suspension controllers, oplev servos**
- Complete optimization and characterization of **MZ** (add bb EOM?)
- Complete optimization and characterization of **MC LSC and ASC**
- Expect new **ISS** in near future
- Expect new **TT FSS** in near future
- Continue optimization and characterization of **PSL FSS, PMC, ISS**
- New **DAQ software** (already at sites) by end of this month
- New **suspension controllers** by end of this month (destined for sites)

Further work on infrastructure (2)

- Prototype new **EPICS readout, eliminate x-connects** (next month or 2)
- **60 Hz and RFI mitigation** (cabling, feedthroughs, etc)
- **Acoustic noise mitigation** on PSL table?
- **Servo output beams** onto sensing PDs?

I know you won't under-estimate the amount of work that goes into all this "infrastructure" development. It's all required for success of our primary task!

There are no major new pieces to be acquired for this phase of work (until DC readout work), but we know from experience that unanticipated tasks / expenses will arise, if only due to inevitable repairs to existing equipment (PSL, vacuum, STACIS, electronics, etc.)

Budget for FY05

- In FY04, budget consisted of:
  - » Salary/benefits/tuition for Miyakawa, Vass, Abbott, Taylor, Ward
  - » $250K Equipment, M&S
    (MZ, electronics, optics, STACIS, repairs, …)
- In FY05, we expect no major budget expense until we begin construction of DC readout equipment
  - » requires a design, proposal, separate request for funding
- But we expect continued need for electronics, optics, computers, repairs, M&S, etc ⇒ $250K.

Summary

- 40m lab nearing completion of instrumenting IFO for lock acquisition of DRFPMI
- We have a plan for acquiring lock and are working towards it steadily
- This requires continued development of infrastructure
  - » PSL, frequency & intensity stabilization, Mach-Zehnder, Digital Suspension Controllers and optical levers, Mode Cleaner, RF distribution, Length Sensing, Alignment Sensing, monitoring & diagnostics, 60 Hz noise mitigation and acoustic noise mitigation, …
- Also continued development of simulation tools and models (Finesse, e2e/DRLIGO, simulink, etc), continued development of lock acquisition strategies, and study of extrapolation from 40m to AdLIGO
- We continue to involve LSC visitors, grad students, REU and undergrad students, in all aspects of our work
- Hope to lock DRFPMI interferometer, automate procedure, and understand noise sources in the next 6 months.
- Hope to move on to DC detection shortly thereafter.