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ISC

Interferometer Sensing and Control`

LSC Meeting
Hannover Germany
October 23, 2007

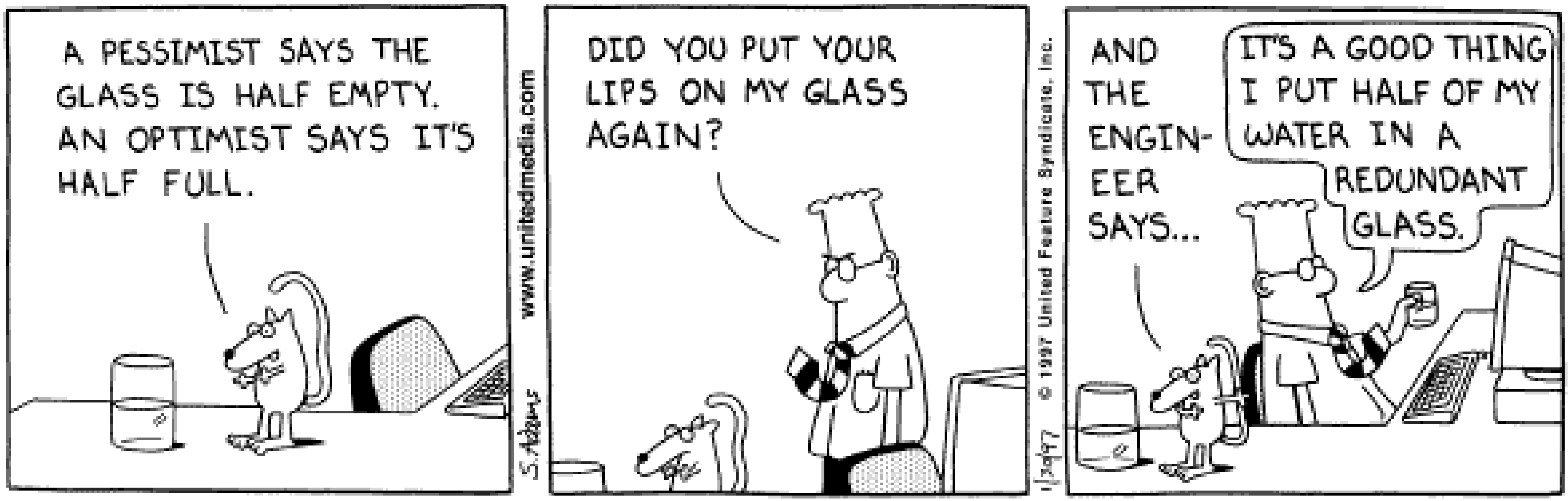
Outline

- Length Sensing and Control (LSC)
  - Current baseline design (9.4 MHz and 47 MHz)
  - Noise modeling for all length loops
- Lock Acquisition
  - Ideas and modeling status
- Angular Sensing and Control (ASC)
  - Requirements and modeling status

Baseline design, Guidelines

- No high RF frequencies (< 100Mhz)
- Good sensitivity for all length DoF
- Should allow the following modes
  - 125 W, no det.: Simple control, 95% of sensitivity
  - 125 W, 8° SR det.: Optimized for NS binaries
  - 4 W, 55° SR detuning: Optimized for BH binaries

Baseline design, Guidelines



Mirror Transmissions

- $T_{ITM} = 1.0\%$ Finesse 620, better for lock acquisition, o.k. for MICH coupling and BS thermal load
- $T_{PRM} = 3.6\%$ Slight over-coupling, better tolerance for unexpected losses
- $T_{SRM} = 12\%$ Optimal tuning for NS and BH binaries, not very critical
  NO narrow-band tuning without SR mirror swap!

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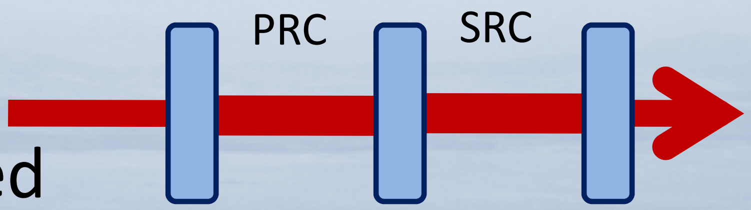
That's Kindergarten!
(anonymous GEO scientist)

Sidebands

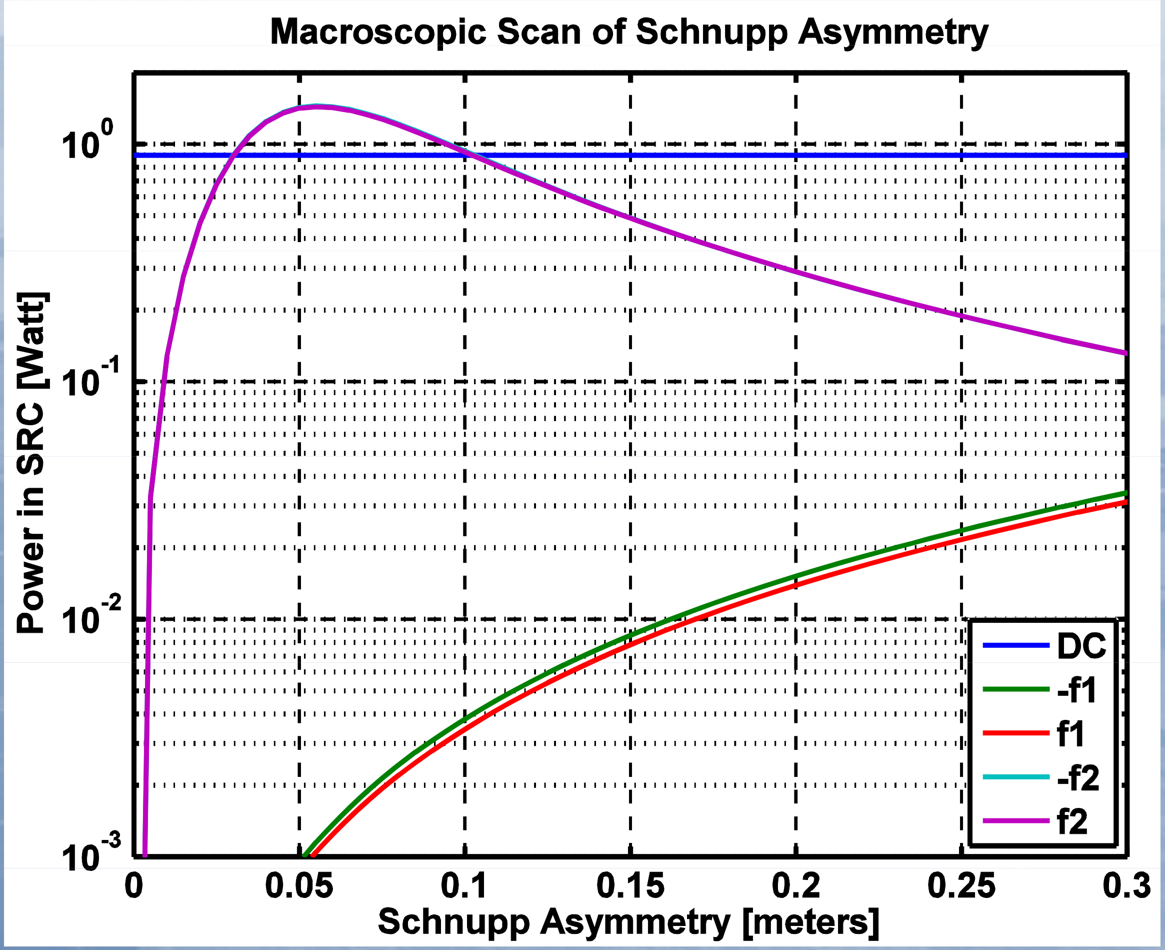
- Power Recycling Sideband: $f_1 = 9.4$ MHz
  - Resonant in PRC only
  - CARM and PRC sensing
- Signal Recycling Sideband: $f_2 = 47$ MHz
  - Resonant in SRC & PRC
  - MICH and SRCL sensing

Schnupp Asymmetry



- Maximize f_2 in SRC
  - Triple cavity critically coupled
- 2 Solutions
  - SRC over- or under-coupled (as seen from PRC)
  - Results in 2 possible Schnupp asymmetries:
    - large : l_{asy} = 1 m T_{asy} = 0.7
    - small : l_{asy} = 5 cm T_{asy} = 1.1e-3
- Picked 5 cm (larger reduction of f_1 in SRC)

Schnupp Asymmetry



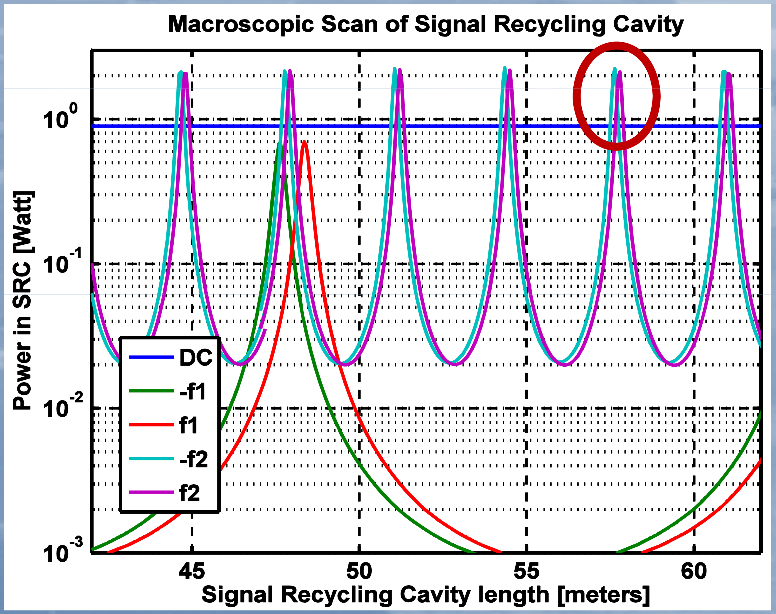
Cavity length

- PRC (stable, folded)

$$l_{\mathrm{PRC}} = \left(N + \frac{1}{2}\right)\frac{c}{2 f_1} = 55.815\mathrm{m}, \text{ for } N = 3$$

- SRC (stable, folded)

$$l_{\mathrm{SRC}} = M \frac{c}{2 f_2}, \text{ but not } Q \frac{c}{2 f_1}$$
$$= 57.410\mathrm{m}, \text{ for } M = 18$$



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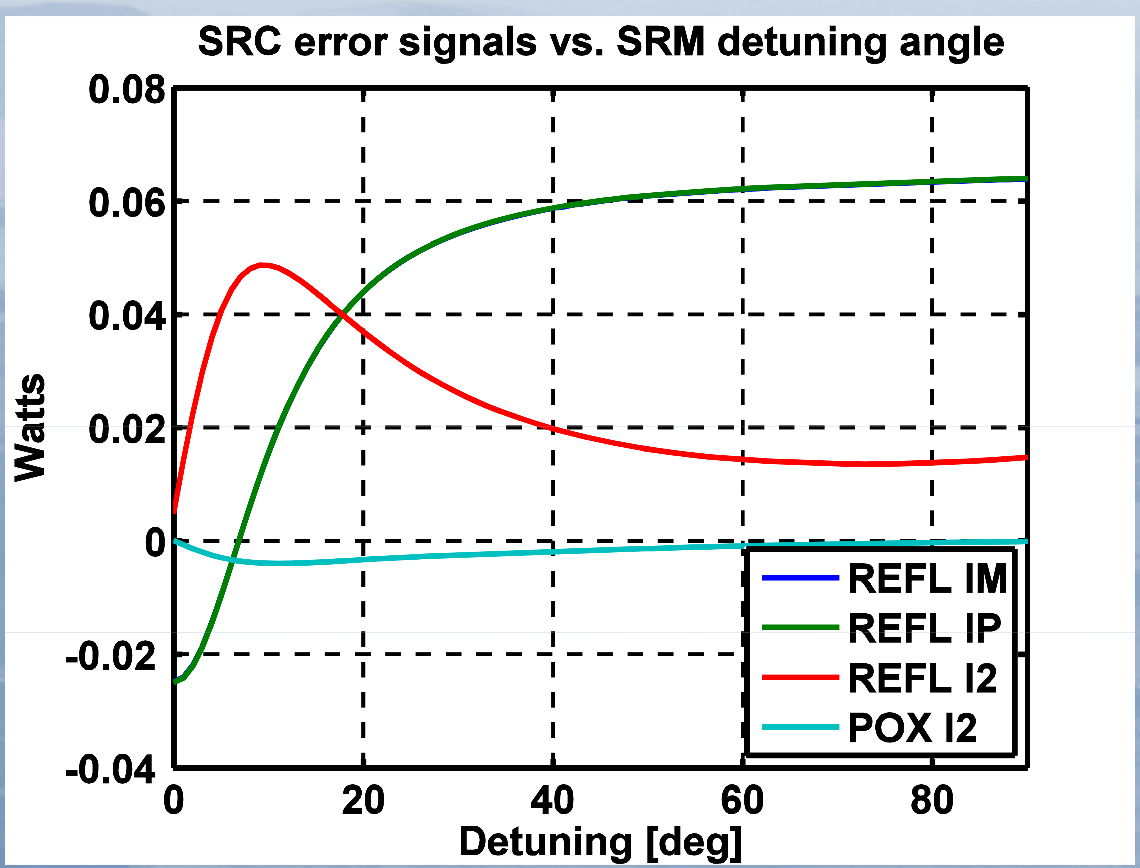
LSC

Error Signals

• DARM	AS DC	DC readout
• CARM	REFL I1	f_1 in reflection
• PRCL	POX I1	f_1 at pick-off
• MICH	POX Q2	f_2 at pick-off ITMX
• SRCL	REFL IM / IP	Demod at $f_2 \pm f_1$
	REFL I2 / POX I2	f_2 any port (no det.)

Error Signals for SRC



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Sensing Matrix in Watt/meter at 1kHz

125 Watt, 8° SR detuning

Port	CARM	DARM	PRCL	MICH	SRCL
AS DC	5.7e+05	3.4e+09	2.5e+06	8.8e+06	9.9e+06
REFL DC	3.8e+06	1.4e+06	1.8e+07	1.9e+06	2e+06
REFL I1	1e+08	2.2e+06	8.8e+07	4.1e+06	2e+03
REFL Q1	1.6e+04	5e+02	5.5e+04	1.4e+04	52
REFL I2	1.2e+07	1e+06	2.3e+07	2.7e+06	9.8e+05
REFL Q2	2.3e+06	2.8e+05	3.5e+06	1.1e+07	7.1e+04
REFL IM	5.4e+04	2.2e+03	2.5e+07	7.3e+05	3.3e+06
REFL QM	1.3e+04	5.4e+03	5.8e+06	2e+06	5.6e+05
REFL IP	5.4e+04	2.2e+03	2.5e+07	7.2e+05	3.3e+06
REFL QP	1.3e+04	5.5e+03	5.8e+06	2e+06	5.6e+05
POX DC	2.5e+03	5.9e+07	2.3e+05	1.5e+05	9e+04
POX I1	8.4e+05	2.7e+06	7.3e+06	6.4e+04	1.1e+04
POX Q1	2.6e+02	2.3e+03	1.2e+03	1e+04	3.6e+02
POX IM	61	21	8.2e+03	7.5e+03	2.8e+04
POX QM	2.4e+02	19	9e+04	7.5e+03	4.9e+03
POX IP	62	21	8e+03	7.6e+03	2.8e+04
POX QP	2.4e+02	19	9e+04	7.3e+03	4.9e+03
POX I2	4.6e+05	1.3e+06	1.5e+06	1.8e+05	1.1e+05
POX Q2	2e+05	6.4e+05	8.2e+05	9.8e+05	1.6e+04

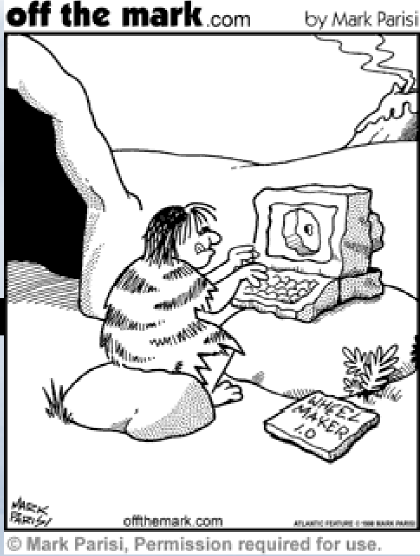
SRC to DARM coupling via Radiation Pressure

- SRC to DARM coupling:
  - SRM displacement noise modulates carrier returning to BS from anti-symmetric side
  - Causes power imbalance in arms
  - Couples to DARM via radiation pressure
- Drives SRM displacement noise requirements
- Requires SRC to DARM correction path (for SRC sensing noise)
- SRC sensing is critical!

Correction paths

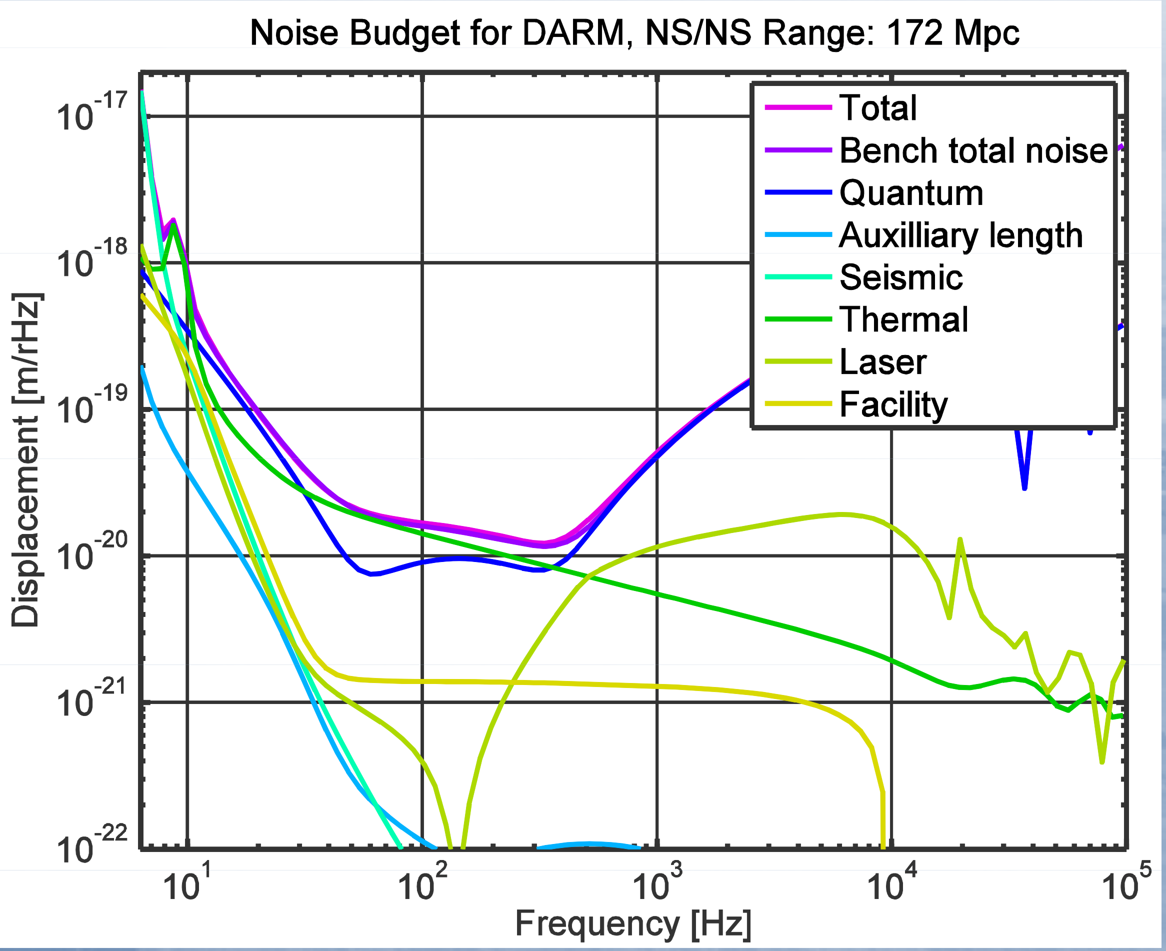
- Old trick: feed know noise in Aux loops to DARM
  - Cancels optical couplings
- Needed with ~1% accuracy for
  - MICH loop (coupling : 1/Finesse)
  - SRCL loop (coupling: radiation pressure)
    - Need to track arm power with 1% accuracy

Noise Modeling



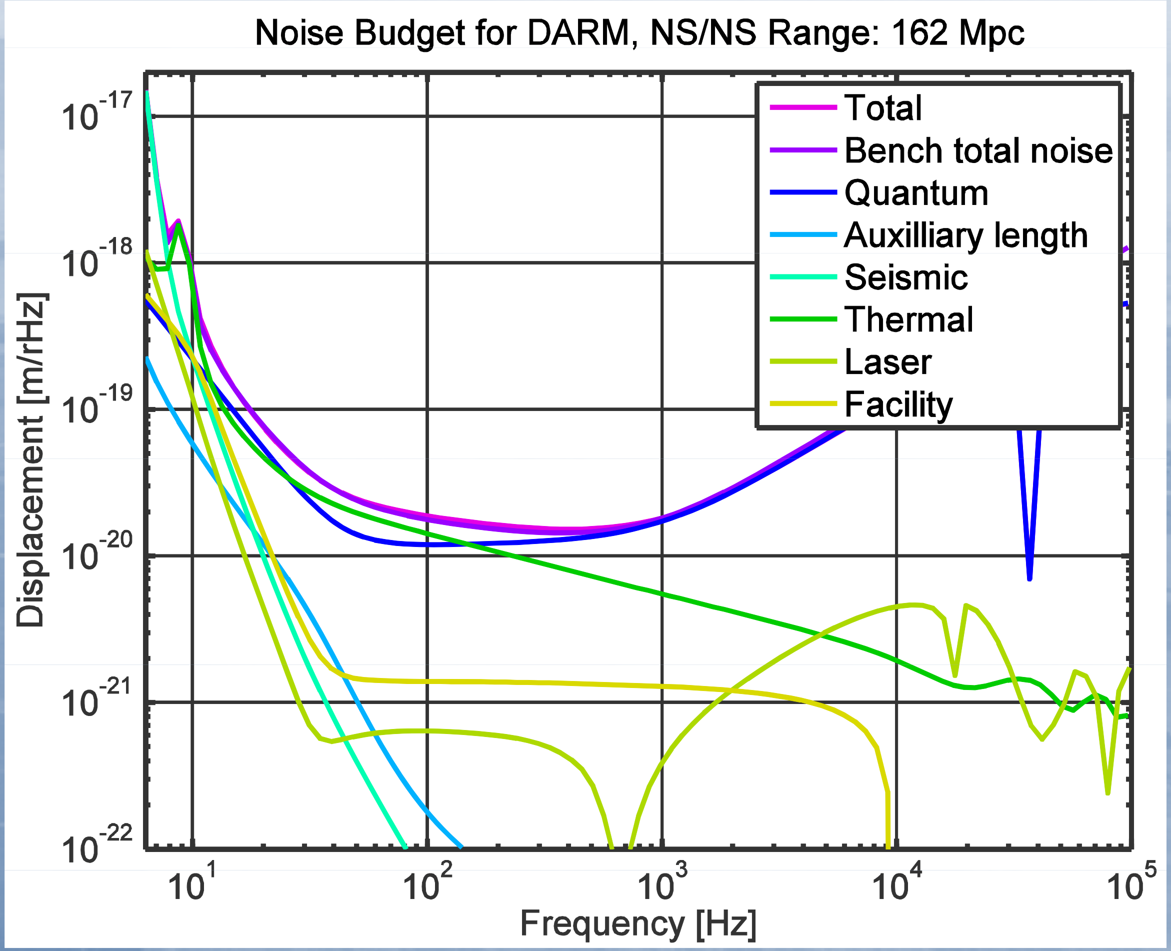
- Done with:
  - Optickle (see Matt Evans' talk)
  - Looptickle add-on for closed-loop system, noise propagation & plotting
- Includes
  - Quantum noise at all ports (Shot & Rad. pressure)
  - Seismic noise at all large optics
  - Thermal (Suspension & Mirror)
  - Laser (Freq., Intensity, Oscillator phase & ampl.)
  - Facility (Residual Gas & Gravity Gradient)

Noise Budget DARM



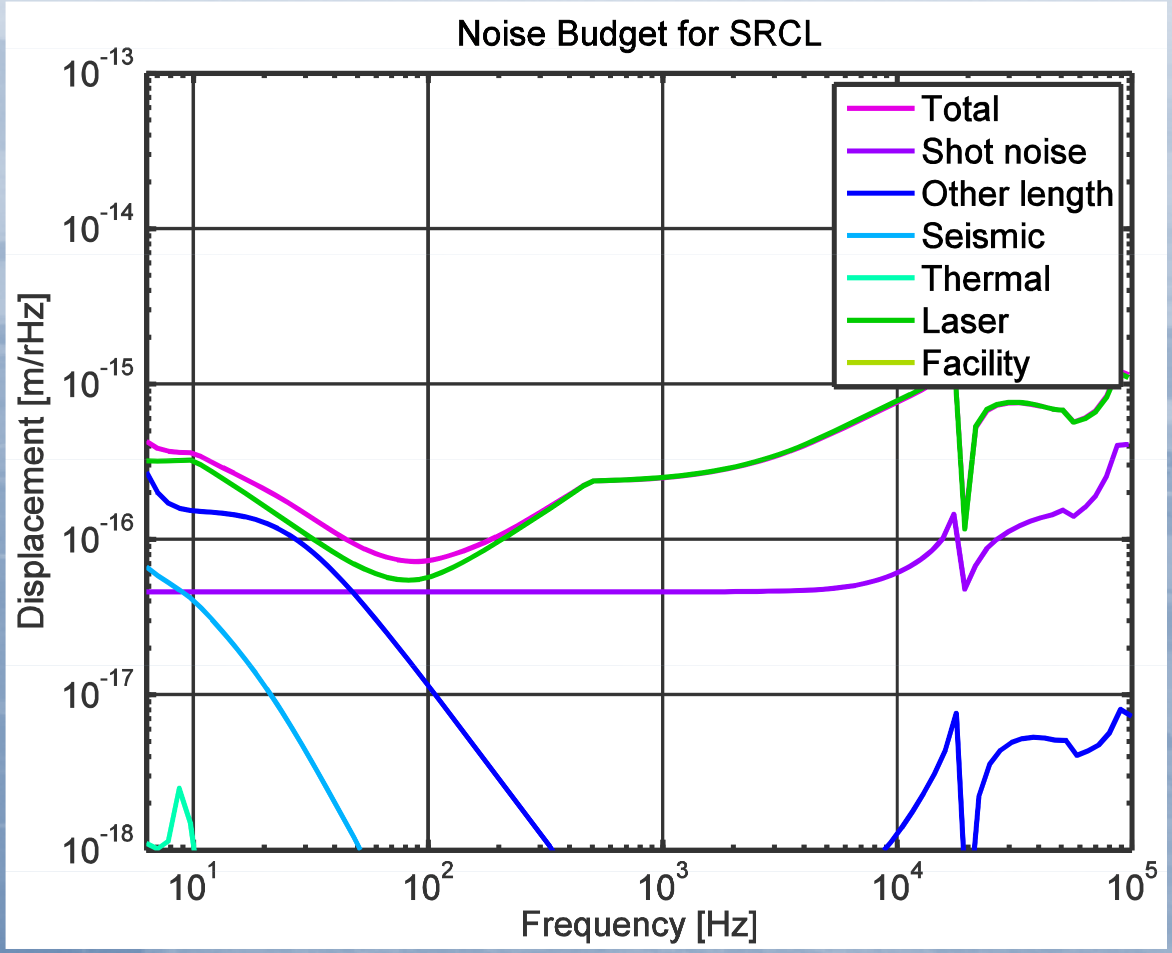
8° SR det.

Noise Budget DARM



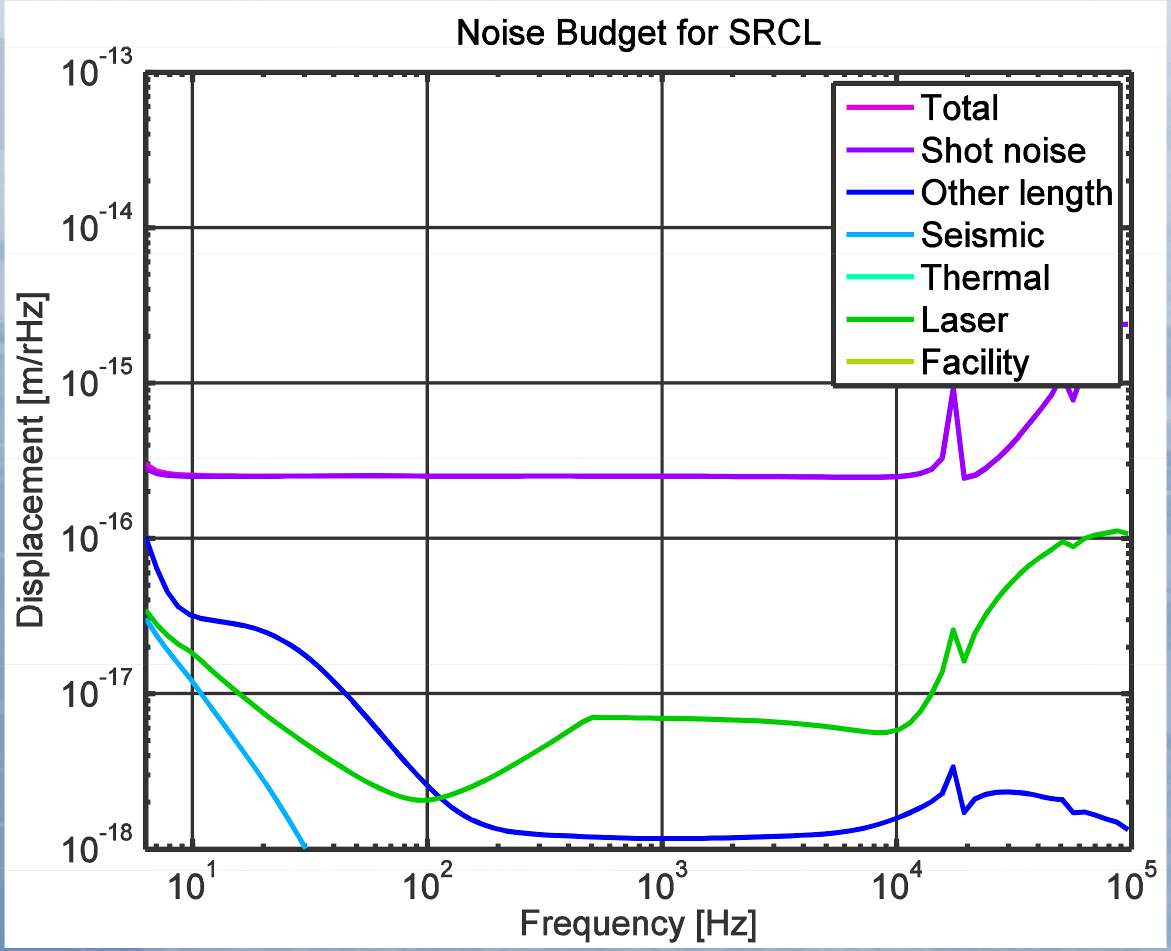
no SR det.

Noise Budget SRCL



8° SR det.

Noise Budget SRCL



no SR det.

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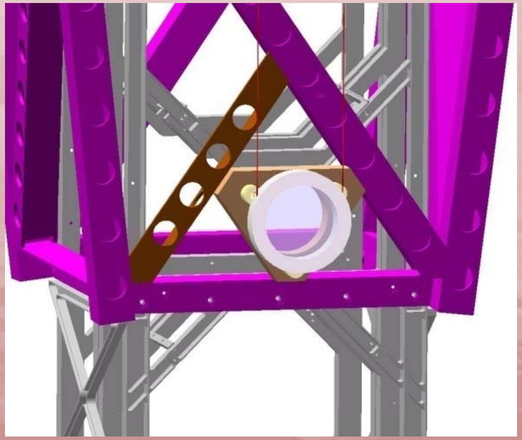
Lock Acquisition for AdvLIGO

(**BroadBand** configuration)

- SPI/ PRN - Scenario in which we can control the arm position within a few nm
- 40m technique: “lock acquisition path” defined by detuning the arm cavities (CARM offset)



Reasonable hypothesis of being able to approach the operating point starting with CARM off resonance and moving it to the working point

→ Search for “good” error signals during the “lock acquisition path” *(Optickle)*

→ Test of the designed control scheme in the time domain *(E2E)*

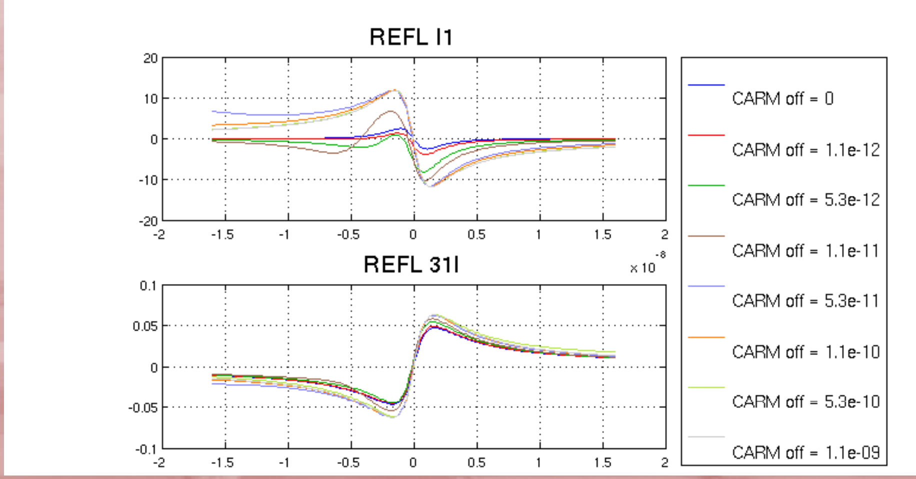
Lock Acquisition for AdvLIGO

(**BroadBand** configuration)

Modeling, by Lisa Barsotti

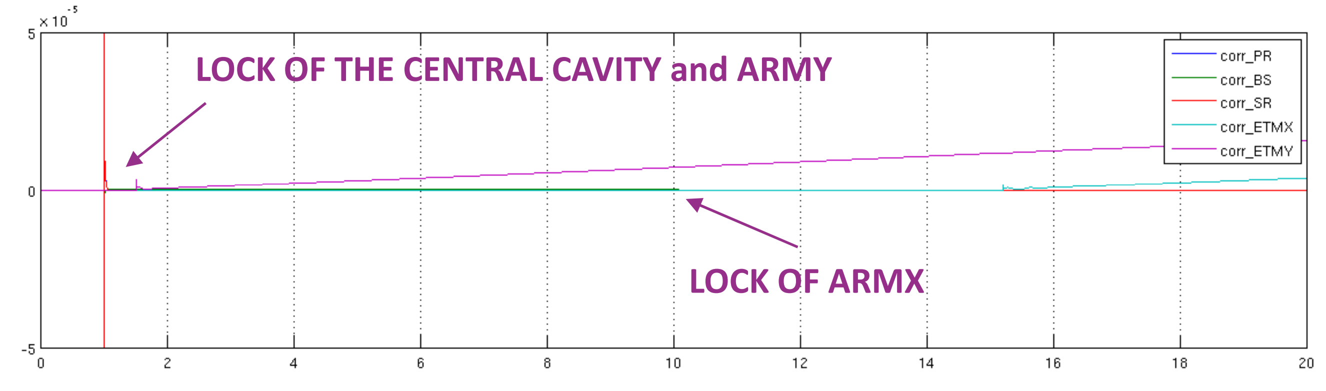
- Starting point for lock acquisition: arm cavities off resonance
- Signals at the reflection port (REFL) demodulated at **$3xf_1$ & $3xf_2$**: good error signals for the central cavity (PRCL, MICH, SRCL)

→ ***independent from arm cavity pos.***



- Locking simulation, using Optickle adiabatically (full lock acquisition sequence test in E2E – *in progress*)

Lock of the cavities off resonance



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ASC Requirements

- RMS stability: 10^{-9} rad RMS (TM's)
  10^{-8} rad RMS (BS, RM's)
  - Beam jitter driven
  - Assures centering: $\Delta l<100\mu m$

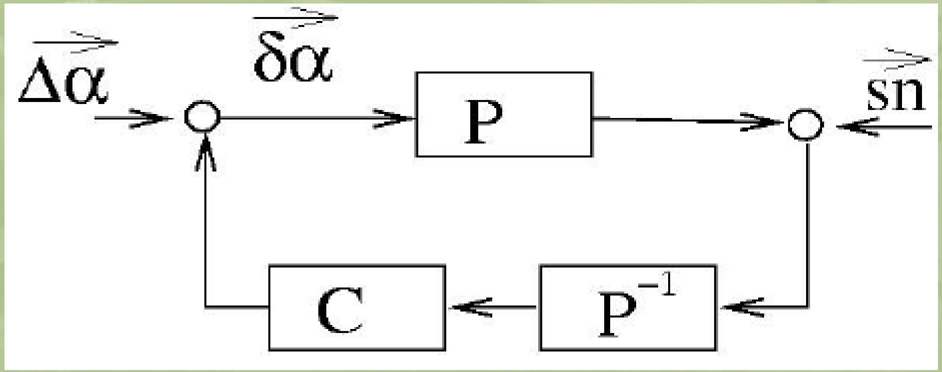
- Same sidebands f_1 & f_2

ASC Requirements

- NS/NS (8° SR detuning)
  - TM: 8x10-15rad/rtHz @ 10Hz, 4x10-16rad/rtHz @ 30Hz, 2x10-16rad/rtHz @ 50Hz
  - RM: 3x10-12rad/rtHz @ 10Hz (independent of beam size!)
- **➔No safety margin!**

ASC modeling

- **Based on Valera Frolov's code**
  - **all signals still scaled with 6cm beam size**
  - results for recycling cavity mirrors need to be multiplied by ~30 (beam size ratio on mirrors)
- **Shot noise: not yet fixed.**
  - Still some factor 2 type uncertainty
  - have theory but not implement it yet



ASC modeling

- **NS/NS Case: Pin= 125W (Current status)**
  - **Loop Gain:**

3Hz	**3**	**RM**	**1**
10Hz	**1**		**0.3**
30Hz	**0.3**		**0.03**

- **Simulation:**

frad/rtHz	Port	Sensor	3Hz	10Hz	30Hz
PR	BP f1	0.8	0.4	0.2	0.03
SR	DP f2	105	52	24	3
DITM	DP f2	0.3	0.26	0.17	0.08
CITM	BP f1	0.9	0.7	0.47	0.22
DETM	DP f2	0.1	0.09	0.06	0.03
CETM	BP f1	1.6	1.2	0.8	0.37

- Requirements(frad/rtHz):
  - 10Hz: 8 (TM) 30Hz: 0.4 (TM) 10Hz: 3000 (RM)

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Conclusion

- LSC: 9.4 MHz and 47 MHz modulation scheme for detuned and non-detuned case looks o.k.
- Locking: Use SPI / PRN for arms
  3f signals
- ASC: First modeling suggests it’s doable, but no margin
  More work needed

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THE END

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LSC

Error Signals

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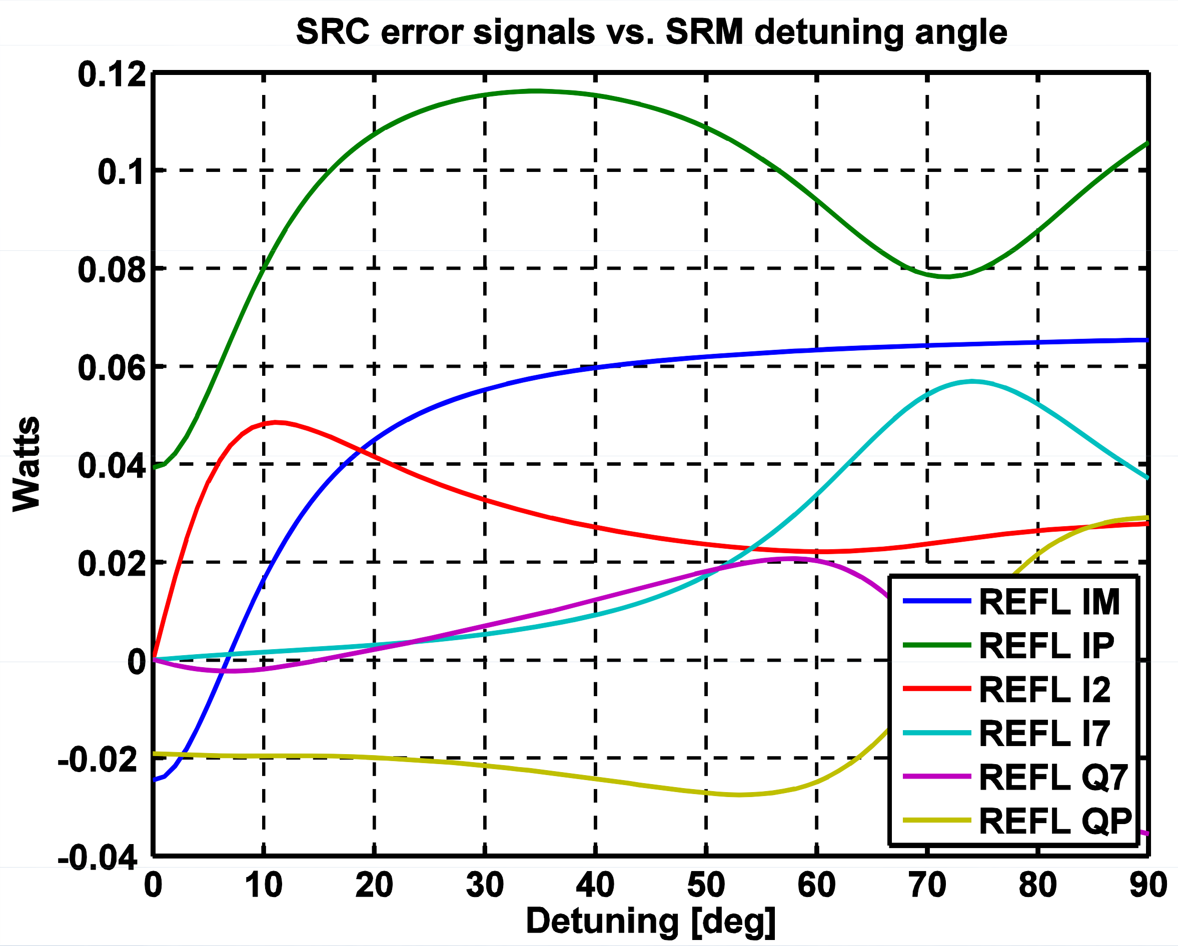
• SRCL	REFL IM / IP	Demod at $f_2 \pm f_1$
	REFL I2 / POX I2	f_2 any port (no det.)
	REFL I7	f_7=7 x f_1; Option for large detuning (55°)

Error Signals for SRC



With
f_7 sideband

Mirror Transmissions