



Advanced LIGO Locking and Commissioning

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work of LLO/LHO Commissioning Teams
(many people!)

AEI/GEO
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Talk Outline

- AdLIGO optical layout and signal ports
- AdLIGO locking scheme: 3f DRMI + green arms
- General Commissioning Goals
- Selected issues/measurements - just for you!



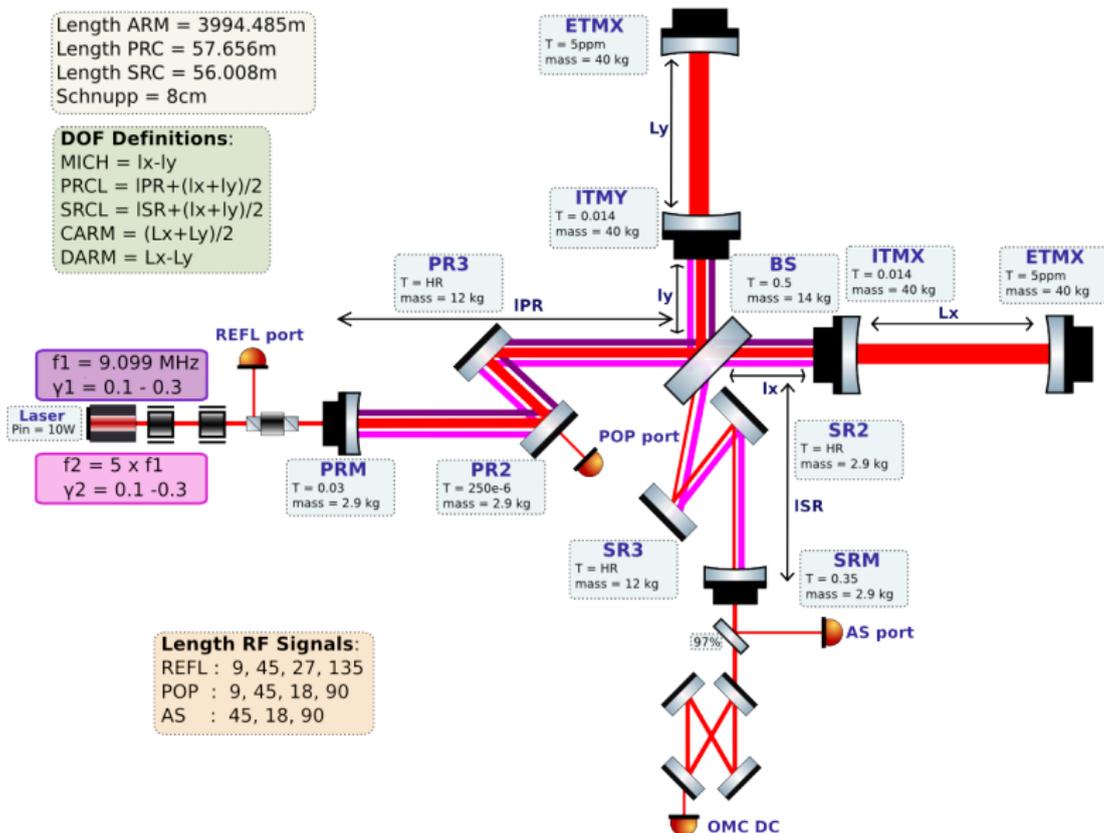


Optical Layout and Signal Ports

Length ARM = 3994.485m
 Length PRC = 57.656m
 Length SRC = 56.008m
 Schnupp = 8cm

DOF Definitions:

MICH = $l_x - l_y$
 PRCL = $l_{PR} + (l_x + l_y)/2$
 SRCL = $l_{SR} + (l_x + l_y)/2$
 CARM = $(L_x + L_y)/2$
 DARM = $L_x - L_y$





Advanced LIGO Locking Scheme (ref: T1000294)

The design length locking scheme is as follows:

- lock arms (CARM and DARM DOFs) via ALS (green laser) off resonance
- lock corner DRMI on 3f signals: MICH, PRCL, SRCL DOFs
- bring arms into resonance by reducing CARM offset
- transition to RF low-noise locking signals
- transition to DC readout

DOF	Sensor for Acquisition	Sensor for Locked	Actuator	Approx UGF
CARM	$\sqrt{TRX + TRY}$	REFL_9I	Frequency Servo	10ish kHz
DARM	TRX - TRY	OMC_DC	ETMX, ETMY	few 100s Hz
MICH	REFL_135Q	POP_45Q	BS + PRM, SRM	few 10s Hz (7-15)
PRCL	REFL_27I	POP_9I	PRM	few 10s Hz (150)
SRCL	REFL_135I, REFL_27I	POP_45I	SRM	few 10s Hz (50)

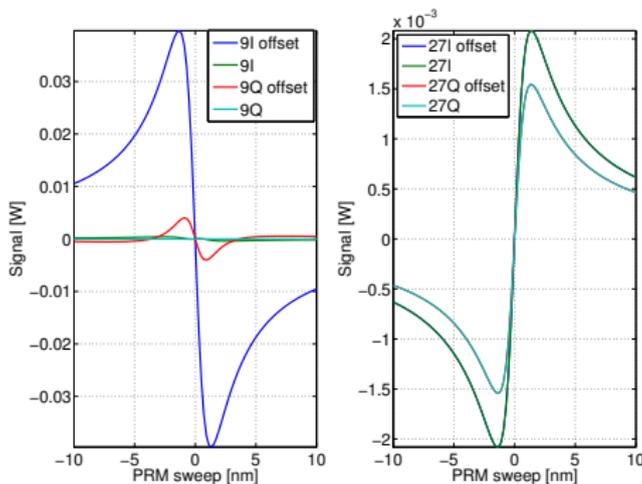


What is 3f DRMI Locking?

Problem: In the power recycling cavity, sidebands resonate but carrier does not until the arms are locked. This means any carrier beat signal will be changing wildly while arms are swinging into resonance.

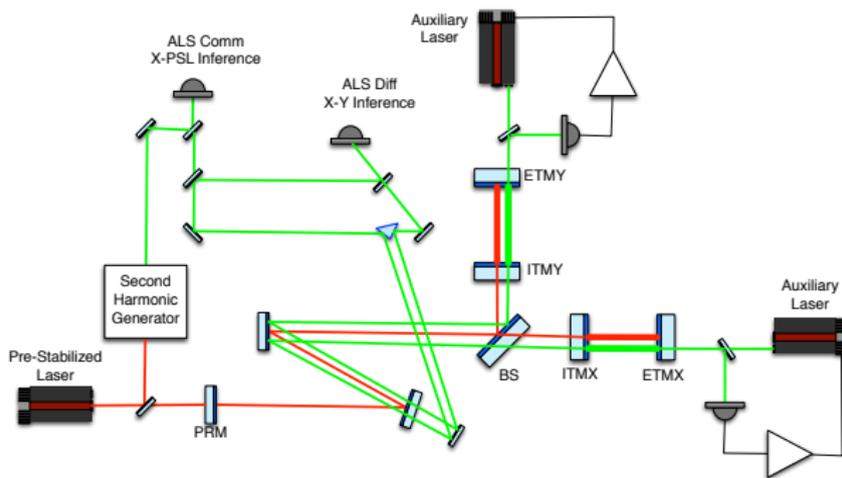
Idea: Lock the corner using only sideband beats (3f should be mostly the beat of 1f and 2f). Signals are weaker but once arms are stably locked we can transition to other less noisy signals.

1f and 3f signals with CARM offset





What is green ALS?



Idea: control the arm DOFs without being affected by corner

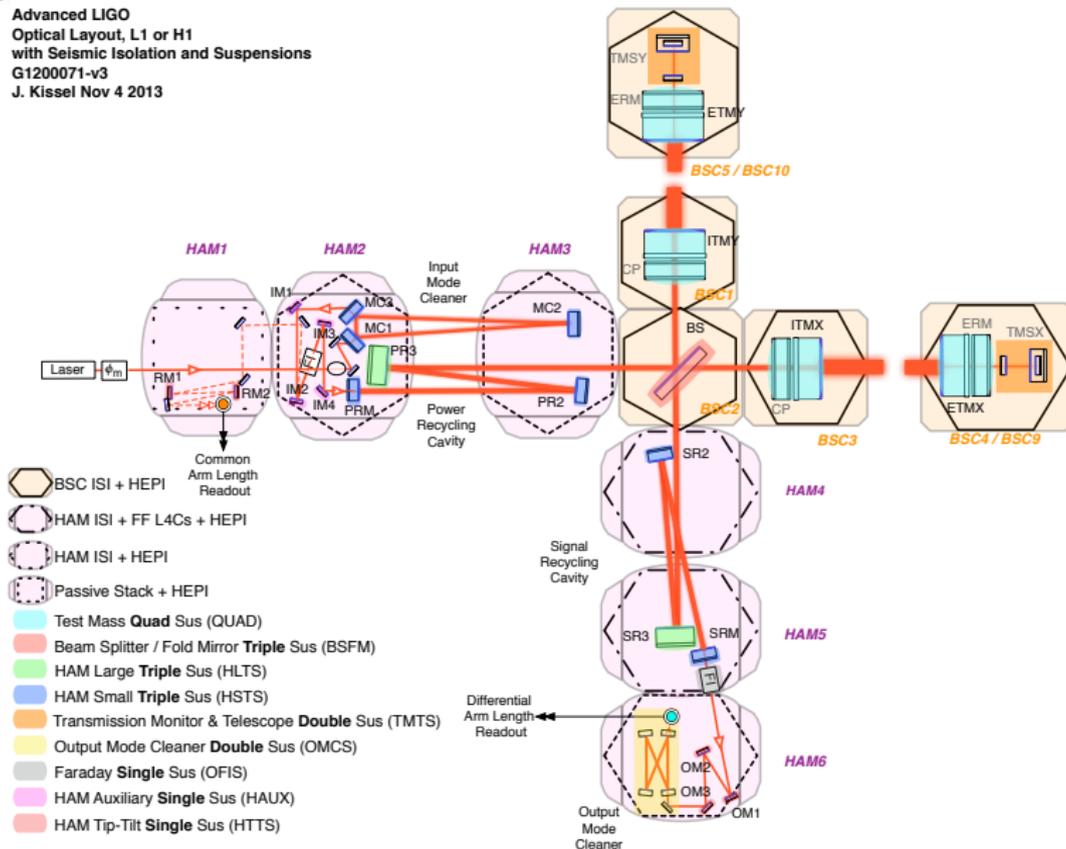
Locking procedure:

- lock green laser at end station to PSL laser (from fiber) 80 MHz apart
- lock green laser to X arm using ETM reflected signal
- lock IR beam to X arm by using the beat of the doubled PSL beam and green beam in corner
- lock DARM by the beat between the two green beams in the corner (160 MHz apart)



Advanced LIGO - in real-er life

Advanced LIGO
Optical Layout, L1 or H1
with Seismic Isolation and Suspensions
G1200071-v3
J. Kissel Nov 4 2013





Commissioning Goals

We must deliver a full interferometer lock, stable for 2 hours.

Corner Locking

- Dual Recycled Michelson (DRMI) lock on 3f signals
 - If possible, characterizations of:
 - PRC, SRC, schnupp assymetry lengths ✓
 - contrast defect, thermal compensation ~
 - recycling gain, mode matching, Q-factors ~
 - angular and length sensing matrices ~
 - OMC and DC readout ✓
 - intensity noise ~
- LLO alog: 11383, 11339

Arm Locking

- using auxiliary green laser to lock the arms with ability to hold on/off resonance
- seismic and suspensions performance

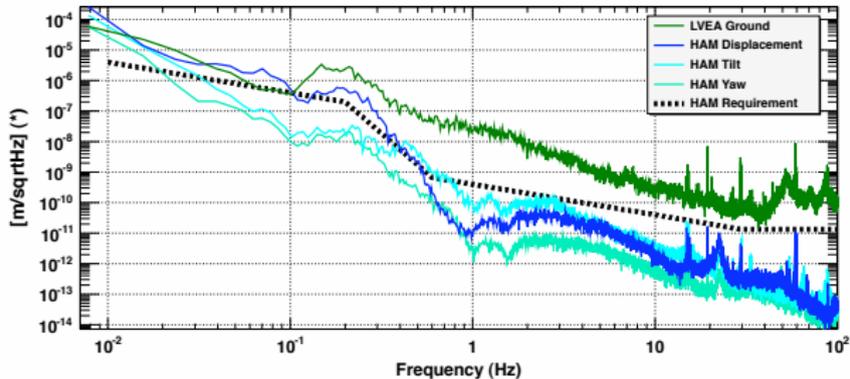
So far we have:

- both: input optics (PSL+IMC)
- LLO: DRMI and X-arm
- LHO: PRMI and X-arm (and previously Y-arm w/ temp. optics)

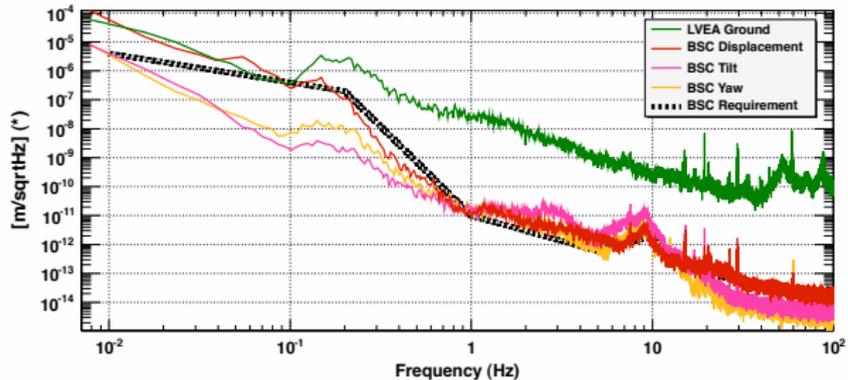


Seismic Isolation - R. DeRosa's cup of tea

HAM ISI Suspension Point Motion (LLO March 2014)



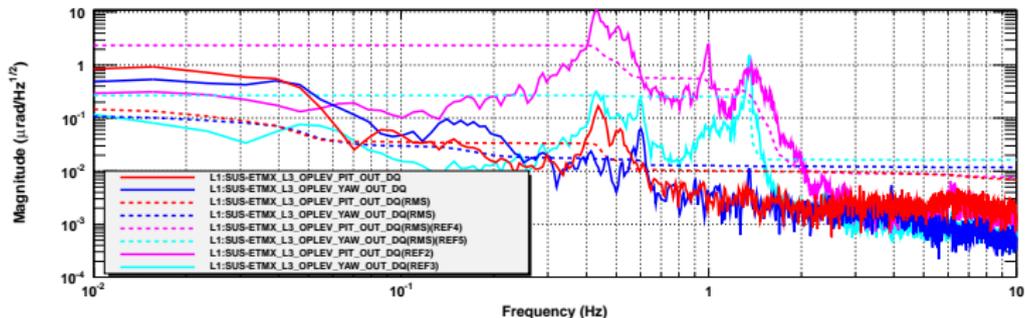
BSC ISI Suspension Point Motion (LLO March 2014)





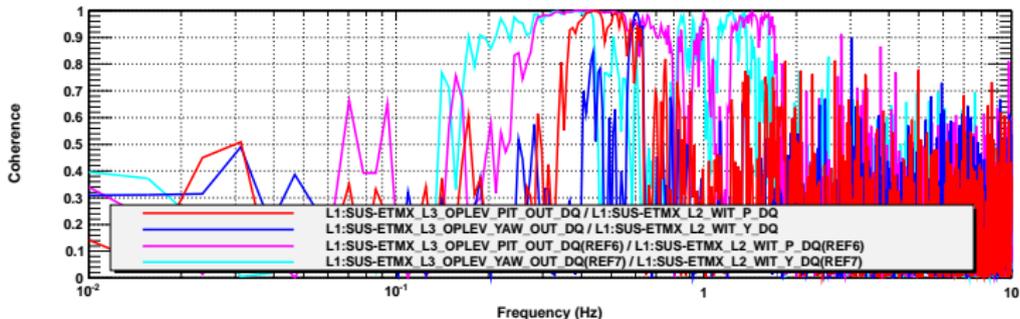
Seismic Isolation - Effect on angular motion

Current is ISI ST1 isolated, REFs are ISI damping only



*T0=31/01/2014 23:34:59

Coherence



*T0=31/01/2014 23:34:59



PRMI Sensing Matrix - my cup of tea

- Optickle and Lentickle modeling of DRMI signals and noise budget
- important for understanding design vs what we have

↓Sensor \ W/m →	MICH (meas.)	MICH (model)	PRCL (meas.)	PRCL (model)	Phase Δ deg
ASAIR 45	5.4e2	5.5e2	2.4e3	7.0e1	86
REFL 9	2.1e4	2.8e4	2.6e6	3.5e6	83
REFL 45	1.3e5	1.3e5	3.1e6	3.4e6	88
REFLAIR 27	6.8e3	1.6e3	5.6e5	1.6e5	81
REFLAIR 135	3.3e3	1.8e3	7.8e4	4.1e4	81

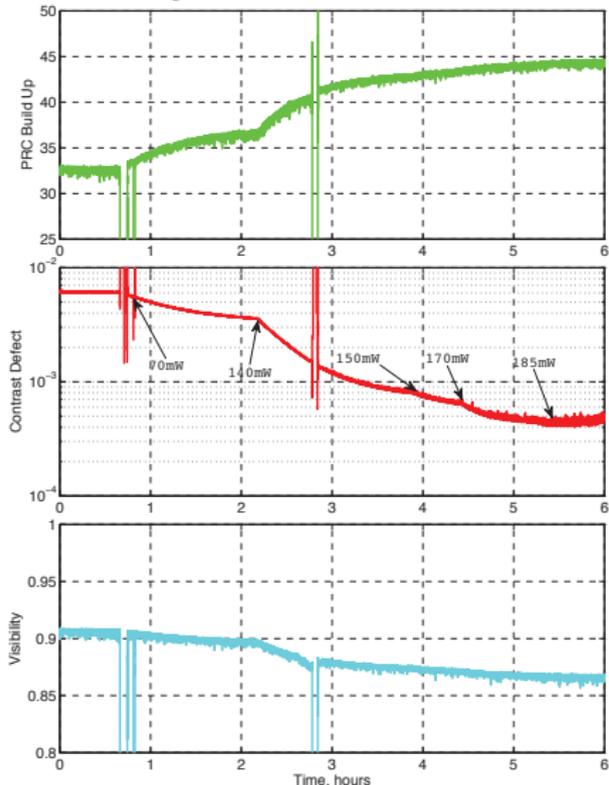
Table: LSC Sensing Matrix in LLO PRMI sideband lock (ref: LLO alog 11381)

- similarly angular sensing matrices measured by K. Kokeyama (ref alog 11385)
- you'd think it's as easy as "shake something - measure something" but ...
 - loops cross-couple, suspensions cross-couple, demod frequencies cross-couple
 - how well do we know DAC to suspension calibration
 - what's the noise of the PDs
 - electronics chain? PD - amplifiers - demodulation - phasing - ADC



TCS and Contrast Defect at LLO

YARM CO₂ laser test in PRMI Carrier Configuration, PSL power = 3W



Contrast defect measured to be $\sim 6e-3$ (best $\sim 6e-4$), while max PRMI buildup was ~ 45 (expected ~ 58).

Due partially to:

- BS map
- ITM ROC mismatch (-80km vs 300 km)
- mode matching designed for 25W
- larger beam so BS baffle clipping

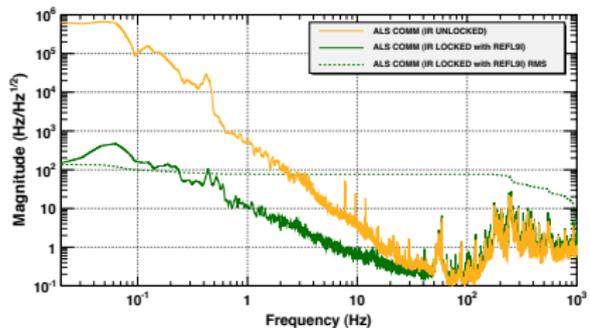
Improvement using ring heaters, but best results with TCS CO₂ central heating. Hence we can correct for beam size and mode matching into the arms.

Hiro Yamamoto modeling predicts slightly worse contrast defect - still under investigation (ref: G1400198)

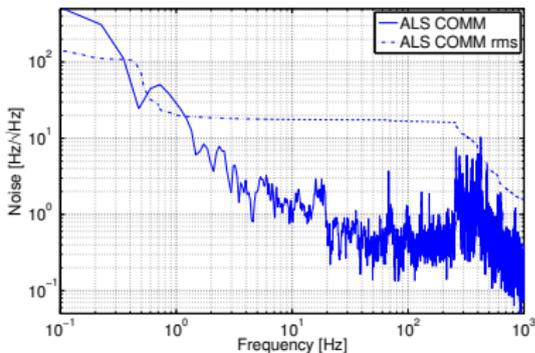


Arm Locking: High ETM Green Transmission

LLO XARM ALS RESIDUAL NOISE - ALS OUT OF LOOP



LHO X-ARM ALS Residual Noise



ETM green transmission closer to 30-50% (instead of spec 3-15%) leading to low finesse cavity ($\times 25$), high angular coupling and more HOM transmission.

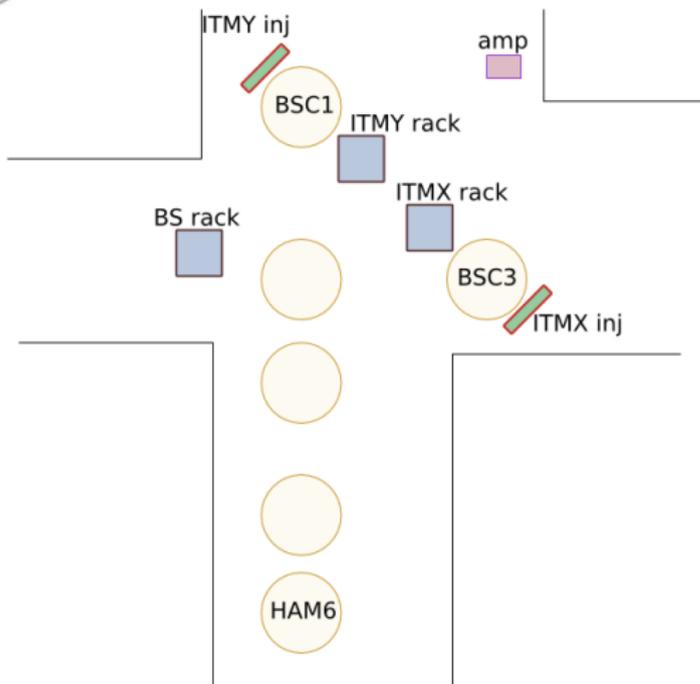
- noise was $\times 10$ lower in Y-arm test at LHO (due to temp. optics)
- arm linewidth ~ 100 Hz but coupled cavity linewidth ~ 1 Hz
- angular noise coupling at low frequencies \Rightarrow ongoing work on implementing green angular controls (WFS)
- proven acoustic coupling at higher frequencies

Alternative lock acquisition modeling efforts under way.

More quantitative explanations of effects: D. Sigg G1400105.



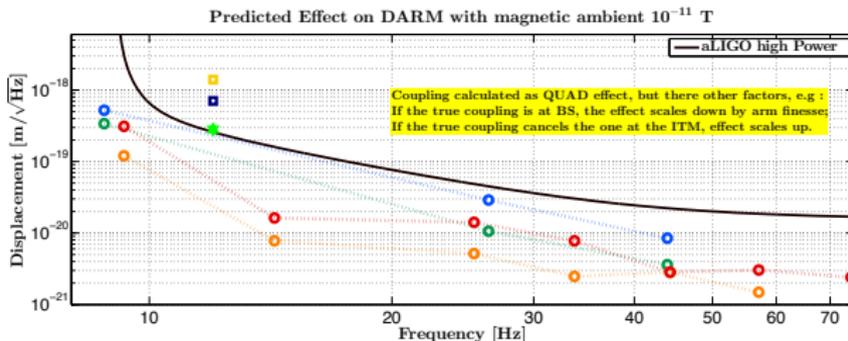
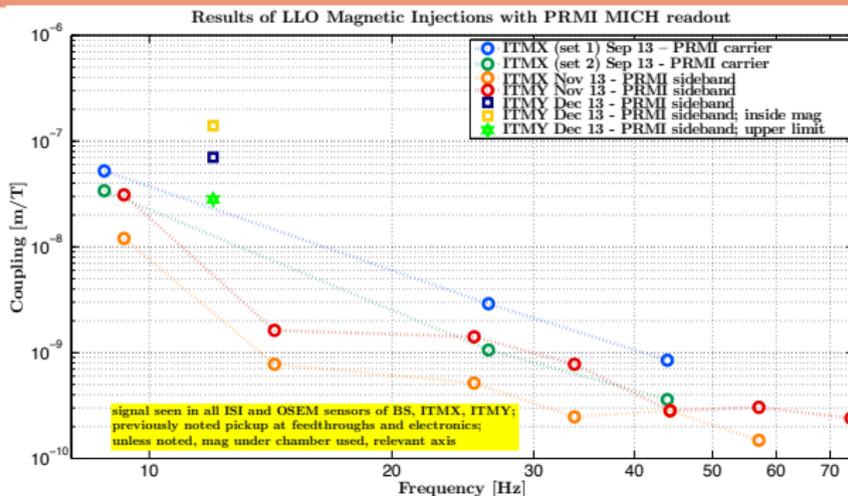
Magnetic Coupling Measurements - setup



- injections separate near ITMX and ITMY- symmetric setup
- witness magnetometer under respective chamber
- amp far away for no interference



Magnetic Coupling Measurements - results





Summary and Next Steps

- Corner subsystems work well (DRMI and PRMI)
- Need to reduce green locking noise (hopefully WFS help and we're clever)

- PRMI + both arms starts at LHO by ~ April
- Full ifo starts at LLO by ~ April

Bonus Video: When SRCL attacks.

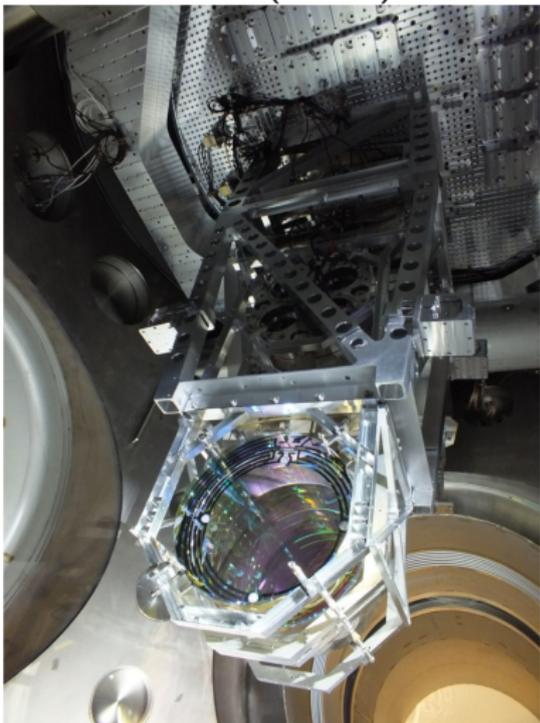
<https://www.youtube.com/watch?v=4K9VHEgEV8s>

ref: LLO alog 11340



Backup: Photos around LLO 1

ITMY (BSC1)

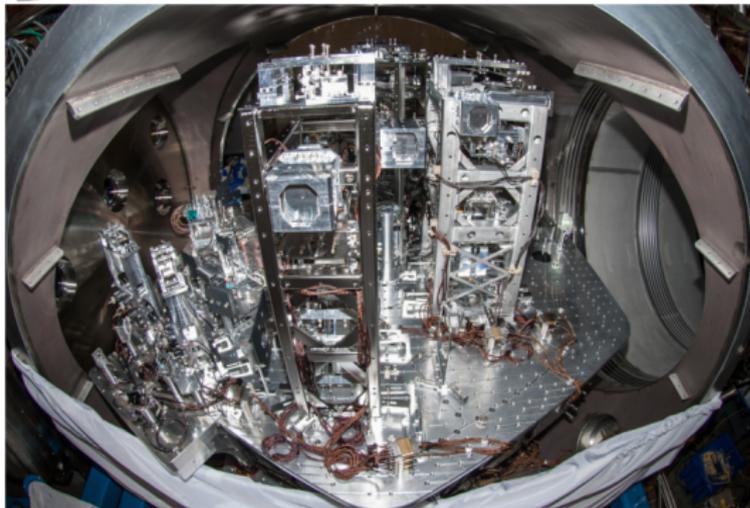


ETMY install (BSC5)



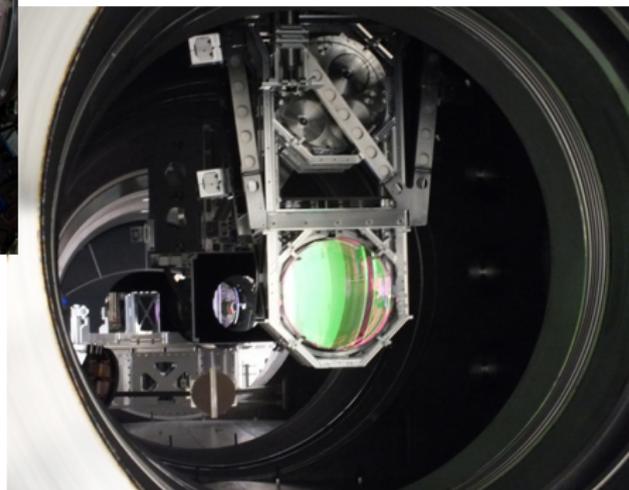


Backup: Photos around LLO 2



HAM2 (busiest table)

BS (BSC2)





Backup: ASC layout

