Highlights from the commissioning of Advanced LIGO

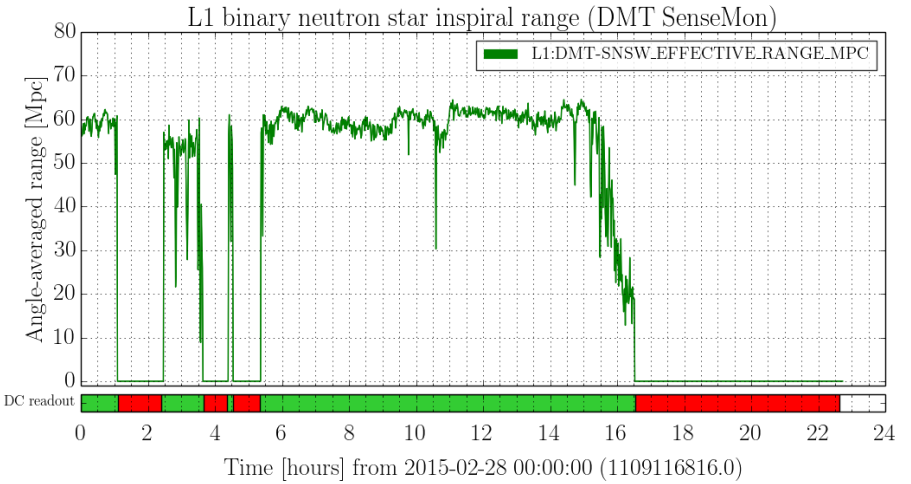
L. Barsotti

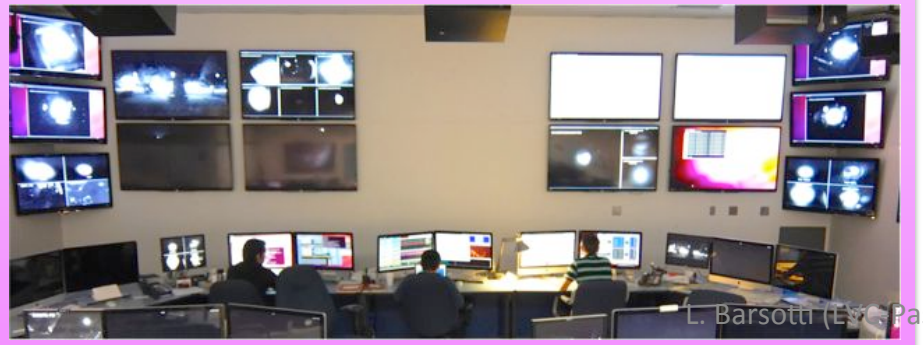
for the Advanced LIGO Team

LIGO-G1500414

Since the last LVC…

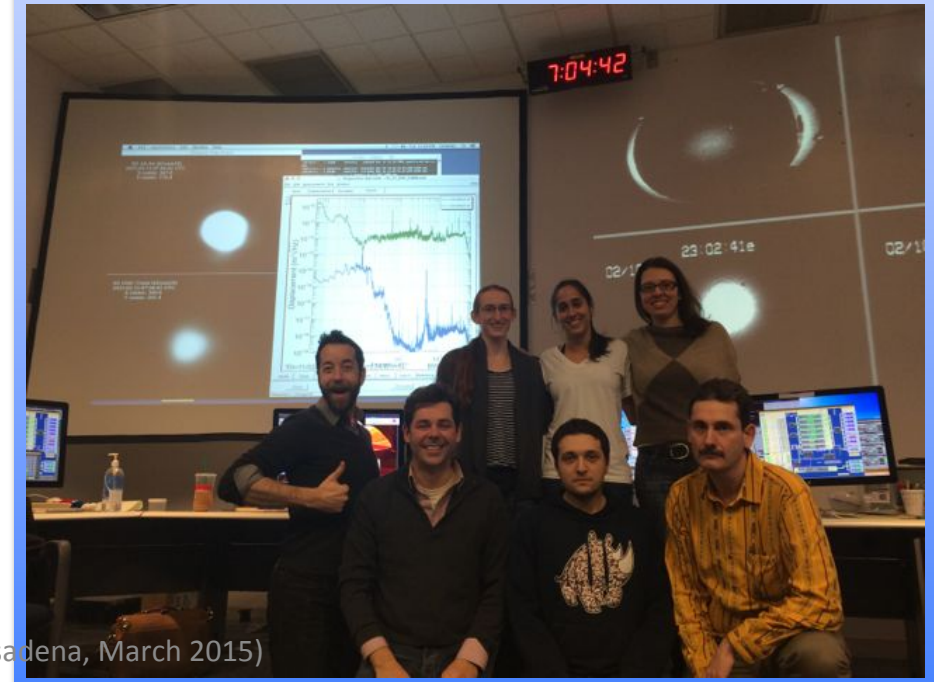
Best L1 Sensitivity = 65 Mpc
10h lock = 20 days of eLIGO



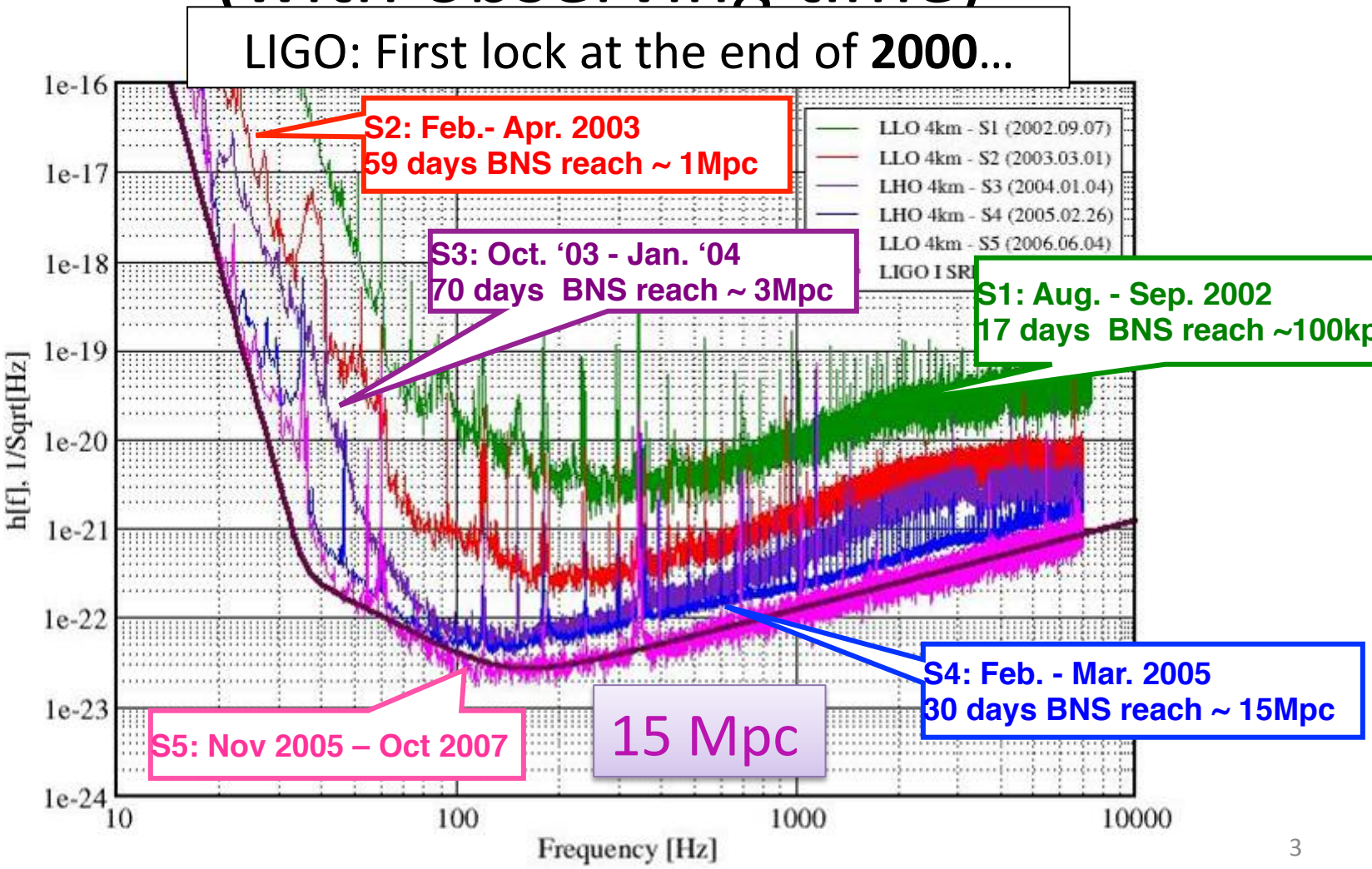


H1 achieved full lock!

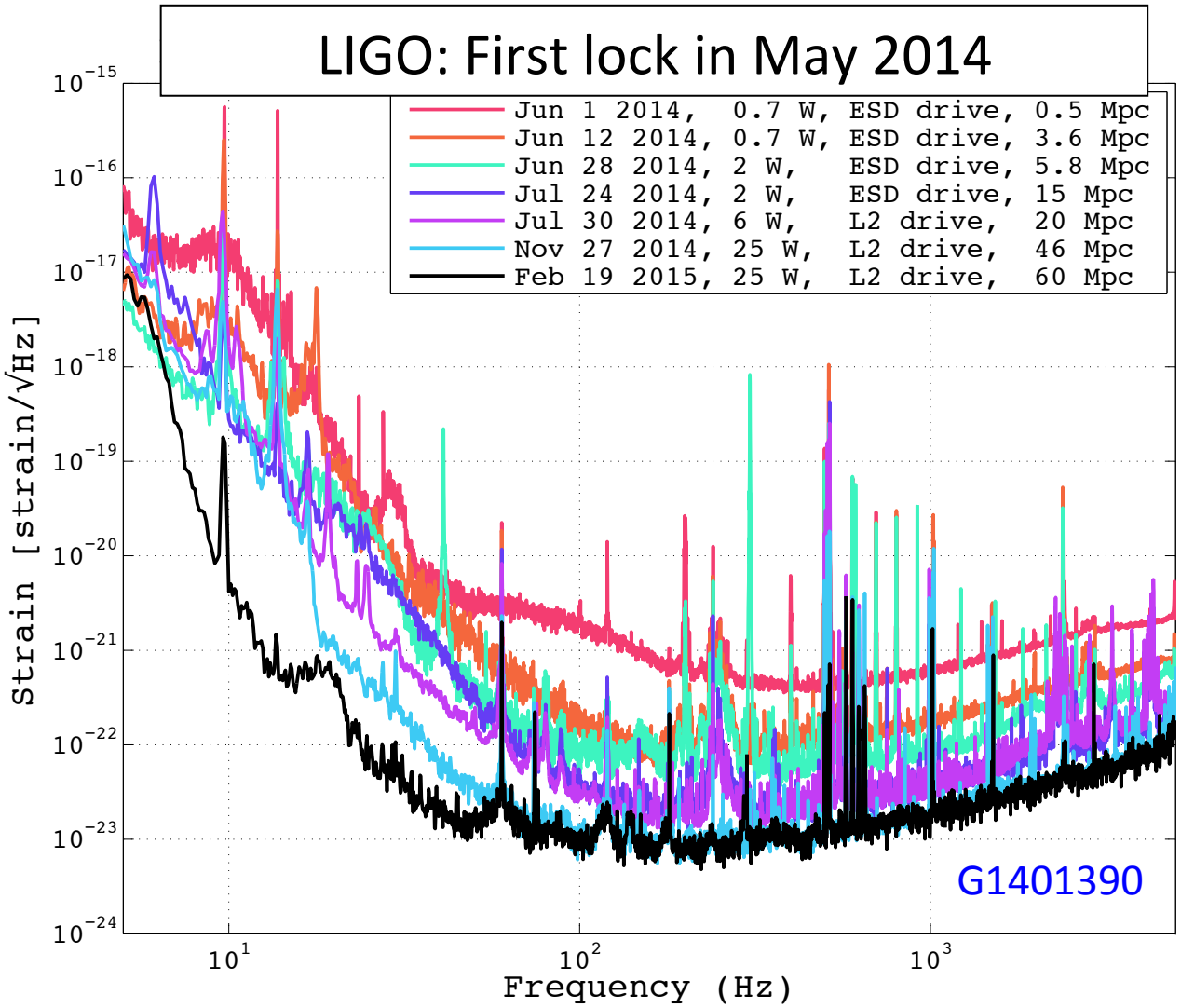
Best sensitivity = 15 Mpc



Reminder from Initial LIGO: from 100 kpc to 15 Mpc in 3+ years (with observing time)



aLIGO L1: from 0.5 Mpc to 60 Mpc in 9 months!



L. Barsotti (LVC-Pasadena, March 2015)

L1/H1 Commissioning Strategy

- L1: "make the noise lower"

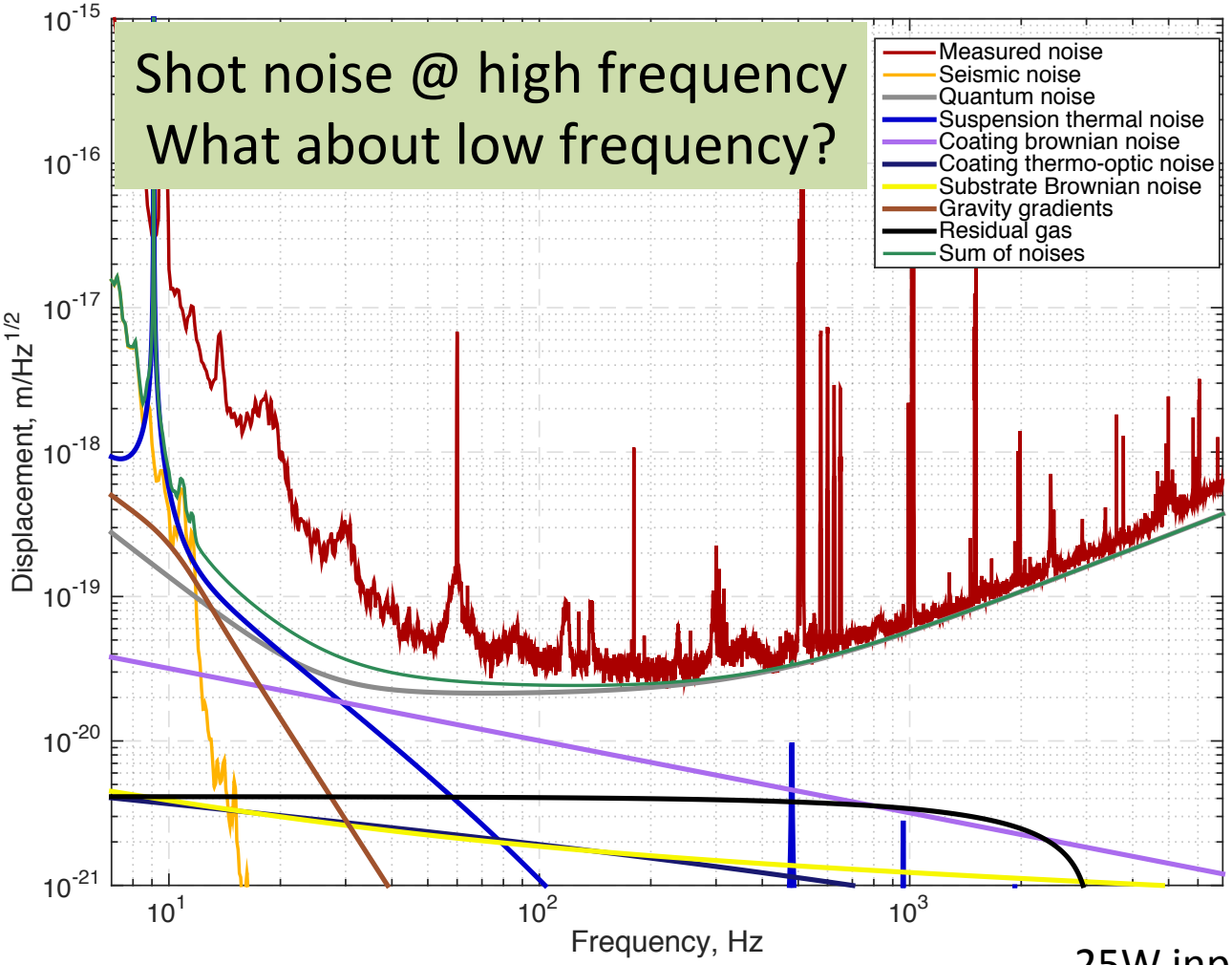
➔ Pathfinder of noise sources/coupling mechanisms
(aLIGO upgrade started ~1 year earlier than in H1)

- H1: Improve the sensitivity following L1 path
- In parallel, both interferometers: work on locking robustness, automation, training of operators

➔ We expect H1 sensitivity to be comparable (at least) to current L1 sensitivity by O1: no reason to believe otherwise at the moment

L1 Noise vs Fundamental Noises

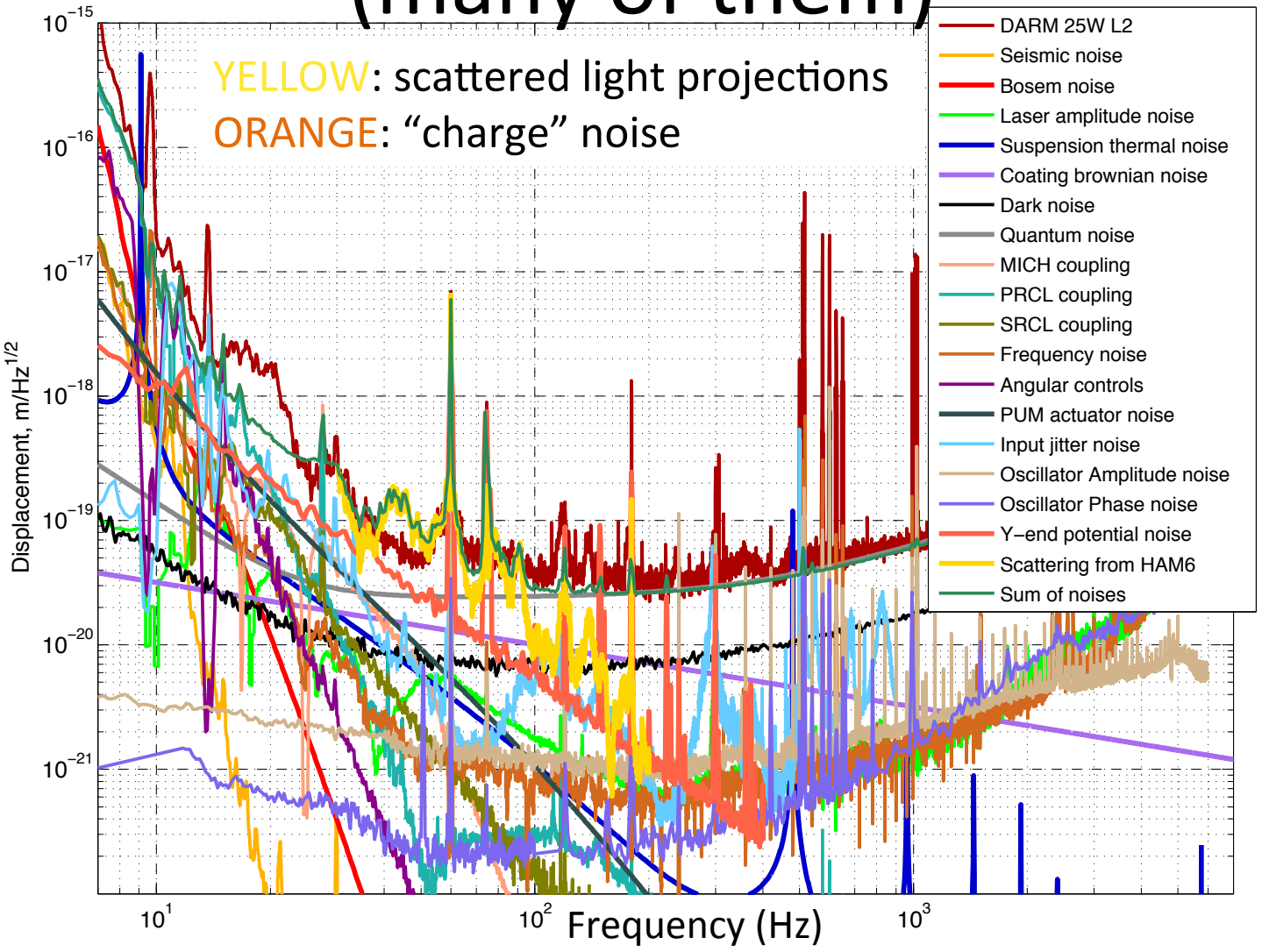
(D. Martynov, **G1500281)**



L. Barsotti (LVC-Pasadena, March 2015)

25W input power
100 kW circulating power

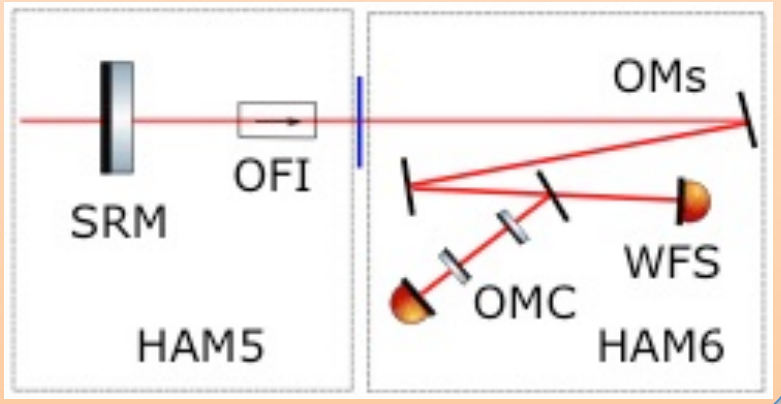
The usual answer: “technical noises” (many of them)



Most “hot” noise sources these days

Scattered light

- Evidence of noise introduced by scattered light
- Investigations focused on the path between the Signal Recycling Mirror and the Output Mode Cleaner



Charge

- Short version of the story: **we have charge on our test masses and this is bad for many reasons**
- In particular, first order interaction with time varying electric fields in the chamber
  ➔ noise in DARM

DISCHARGE effort on going RIGHT NOW at LLO

R. Weiss, G1500264

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Scattered light

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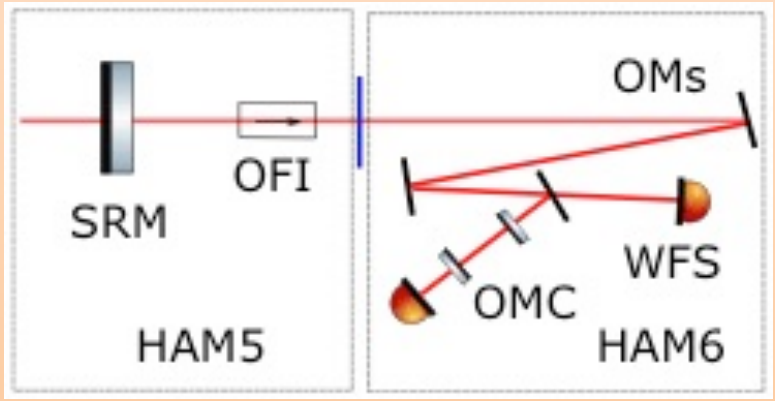
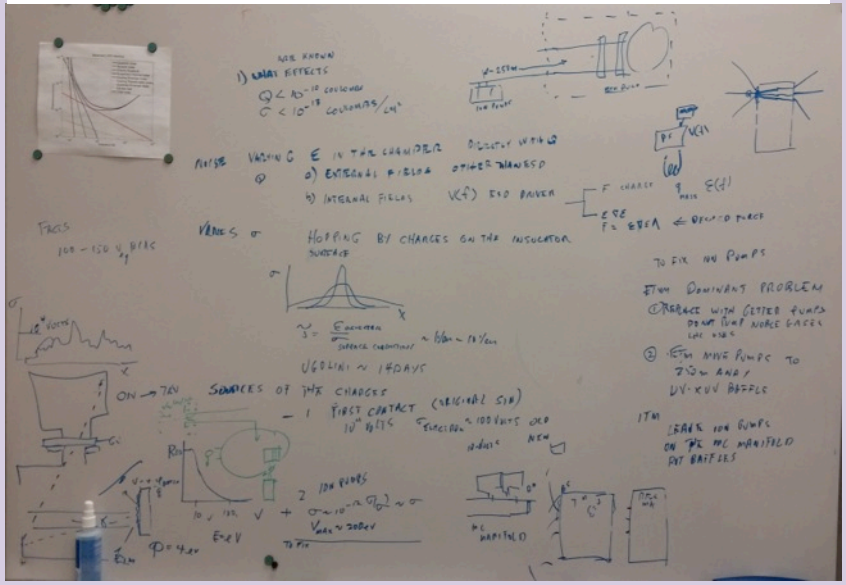


Charge

Long version of the story: ask Rai

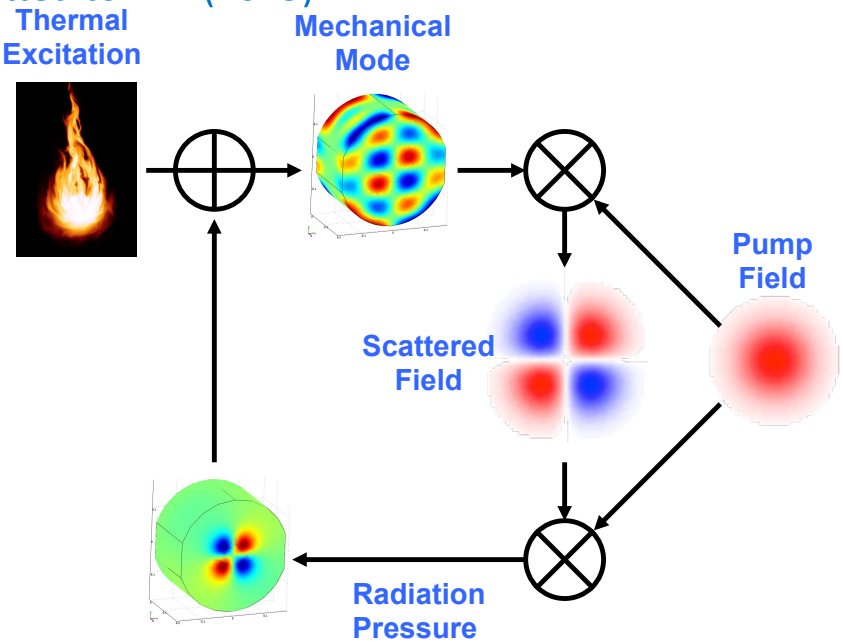


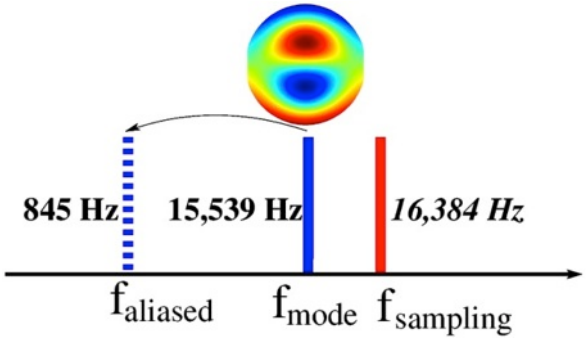
R. Weiss, G1500264

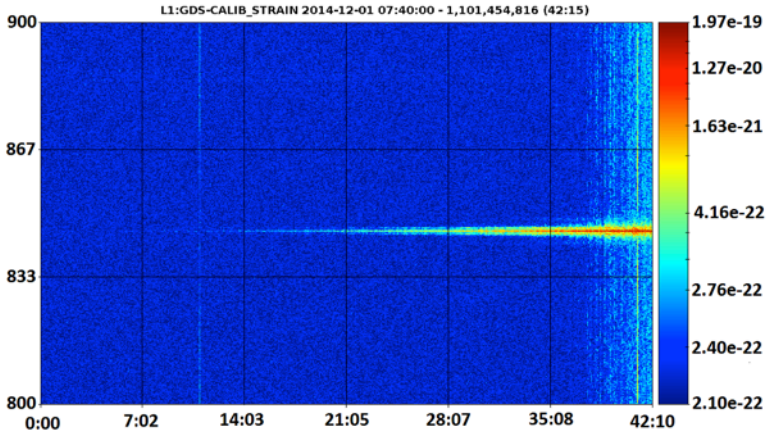
Observed, long expected, problem: parametric instabilities (S. Gras, G1500283)

M.Evans, S. Gras, et al., "Observation of Parametric Instability in Advanced LIGO", arXiv: 1502.06058, submitted to PRL (2015)

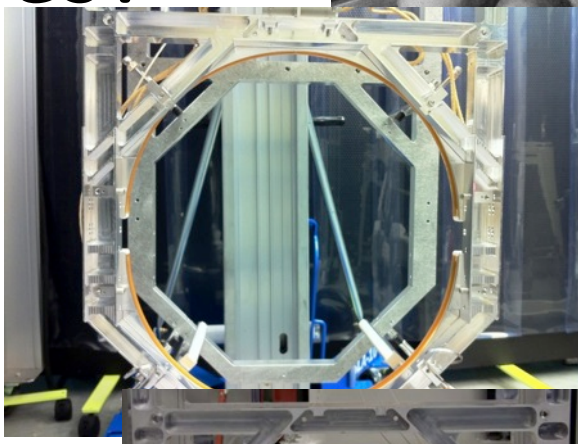
- ✧ Very well understood mechanism: mechanical mode of test mass driven by (classical) radiation pressure
- ✧ More likely to happen with higher the power stored in the arm cavities
- ✧ Parametric instability @ 15.54 kHz observed for the first time in L1 in December
- ✧ Effect is a huge line aliased in band (843 Hz) which saturates the controls

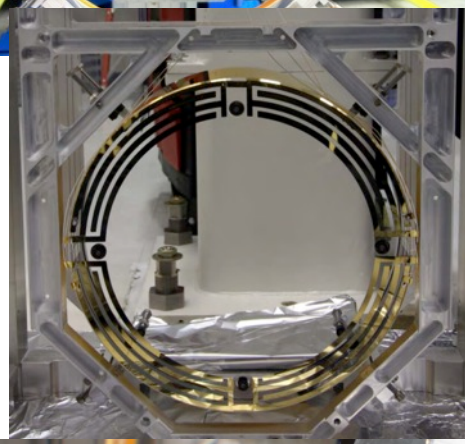






What can we do about parametric instabilities?





0. Lower the power → DONE
1. Break "instability" by slightly change radius of curvature of optics → DONE
2. Actively damp the instability by using electro-static actuators → tried on MIT suspension prototype, good for small number of modes

   J. Miller, et al., *Phys. Lett. A*, **375**, 788 (2011)
3. Attach passive dampers to each test mass → tried on MIT prototype, not active control required, BUT stringent thermal noise requirements on materials

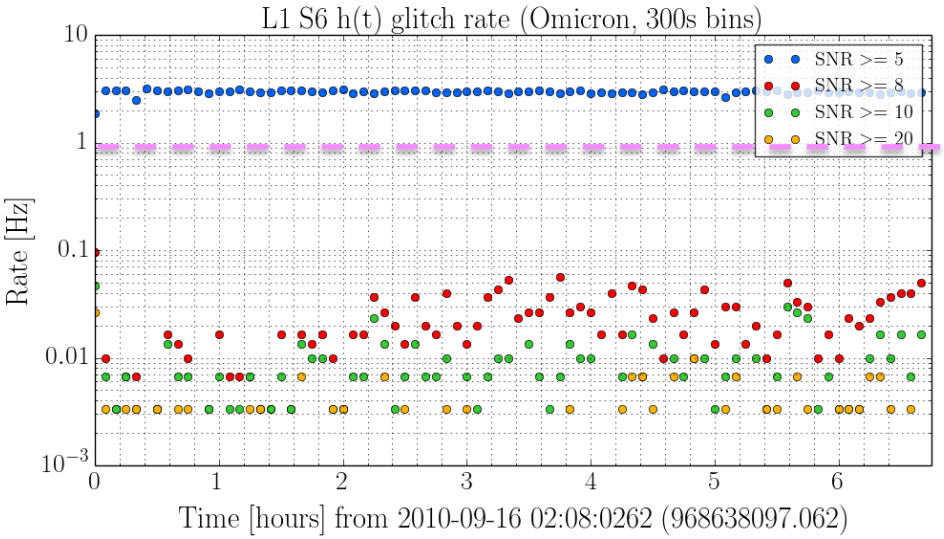
   S. Gras et al., arXiv:1502.06056, (2015)

What can we say about glitches?

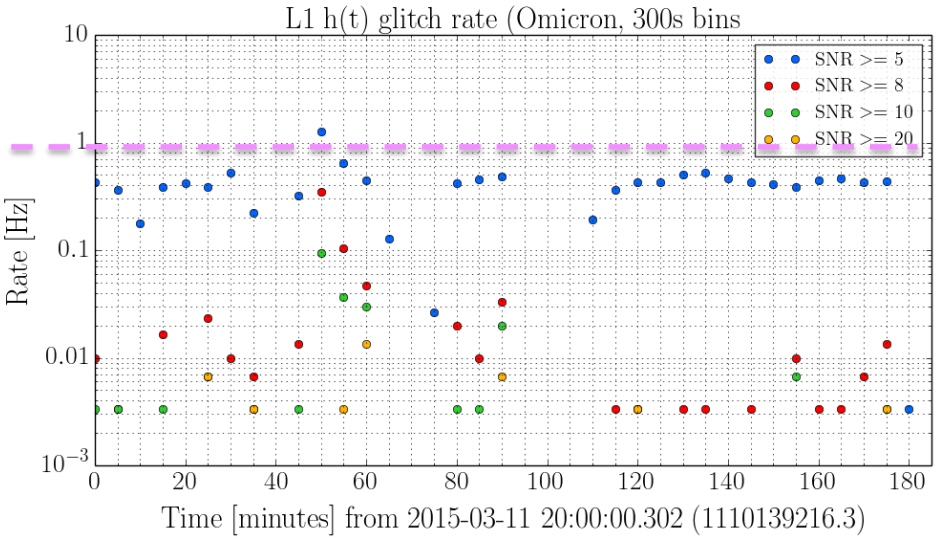
Where we are with respect, for example, S6?

Answer: Laura Nuttall, Josh, et al (G1500259)

S6

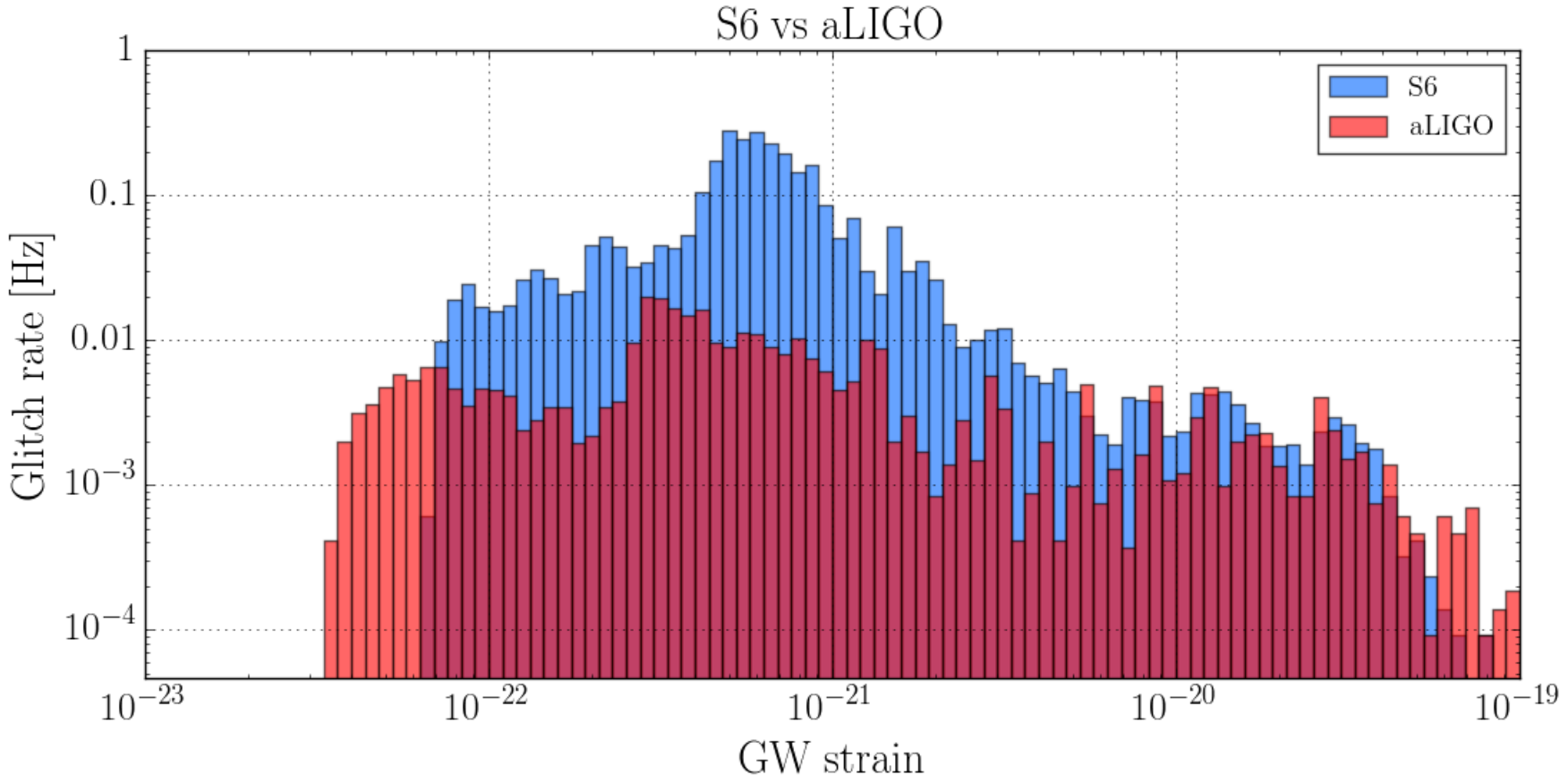


aLIGO L1



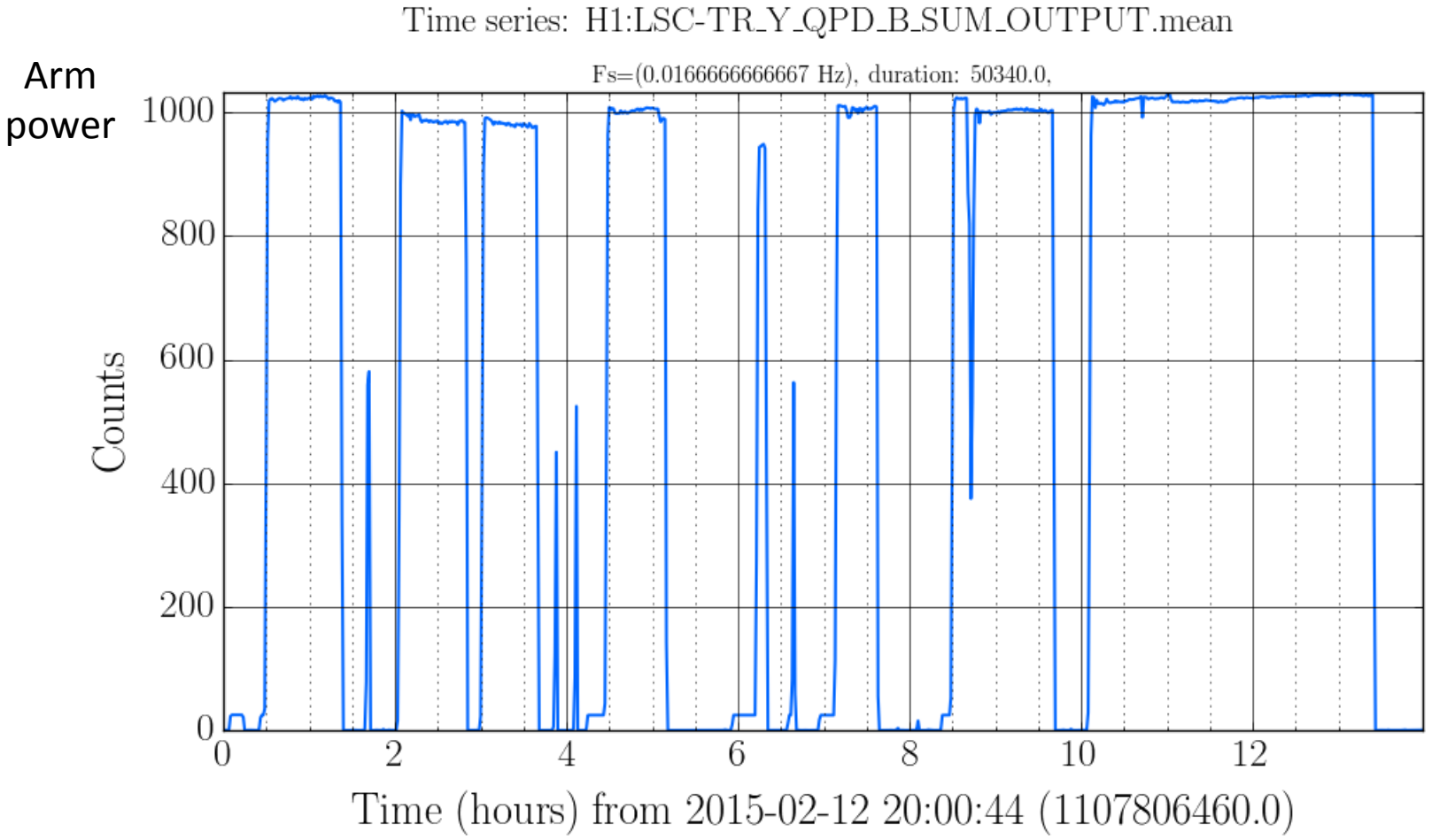
Successful commissioning + DetChar campaigns against glitches over the past months

S6 vs aLIGO glitch comparison
Duncan Macleod



Progress @ Hanford

Just a few days after first stable lock in February… several hours of reliable lock

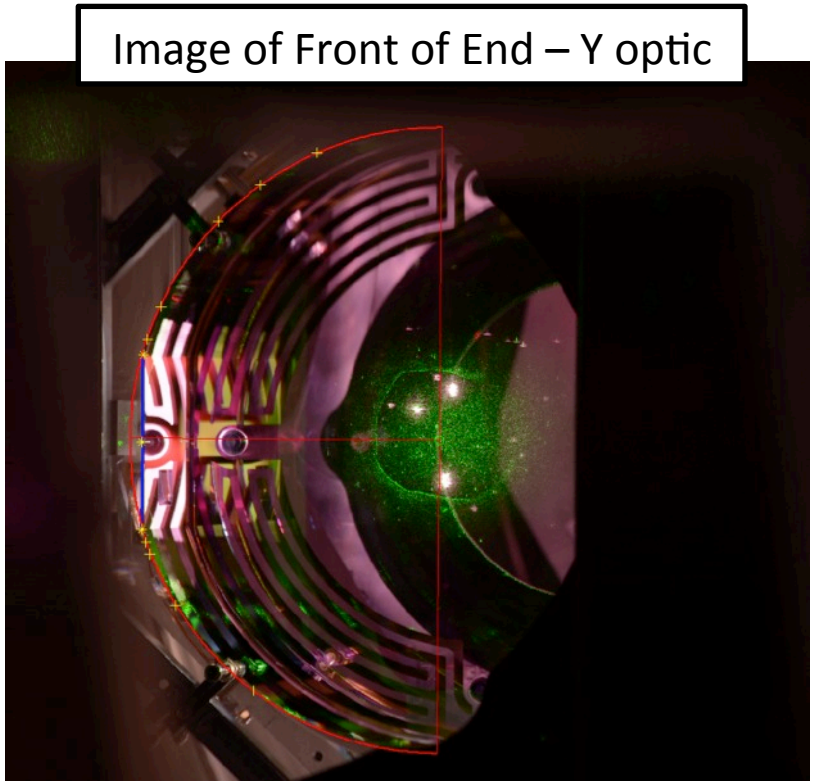


First full lock achieved in early December, BUT…

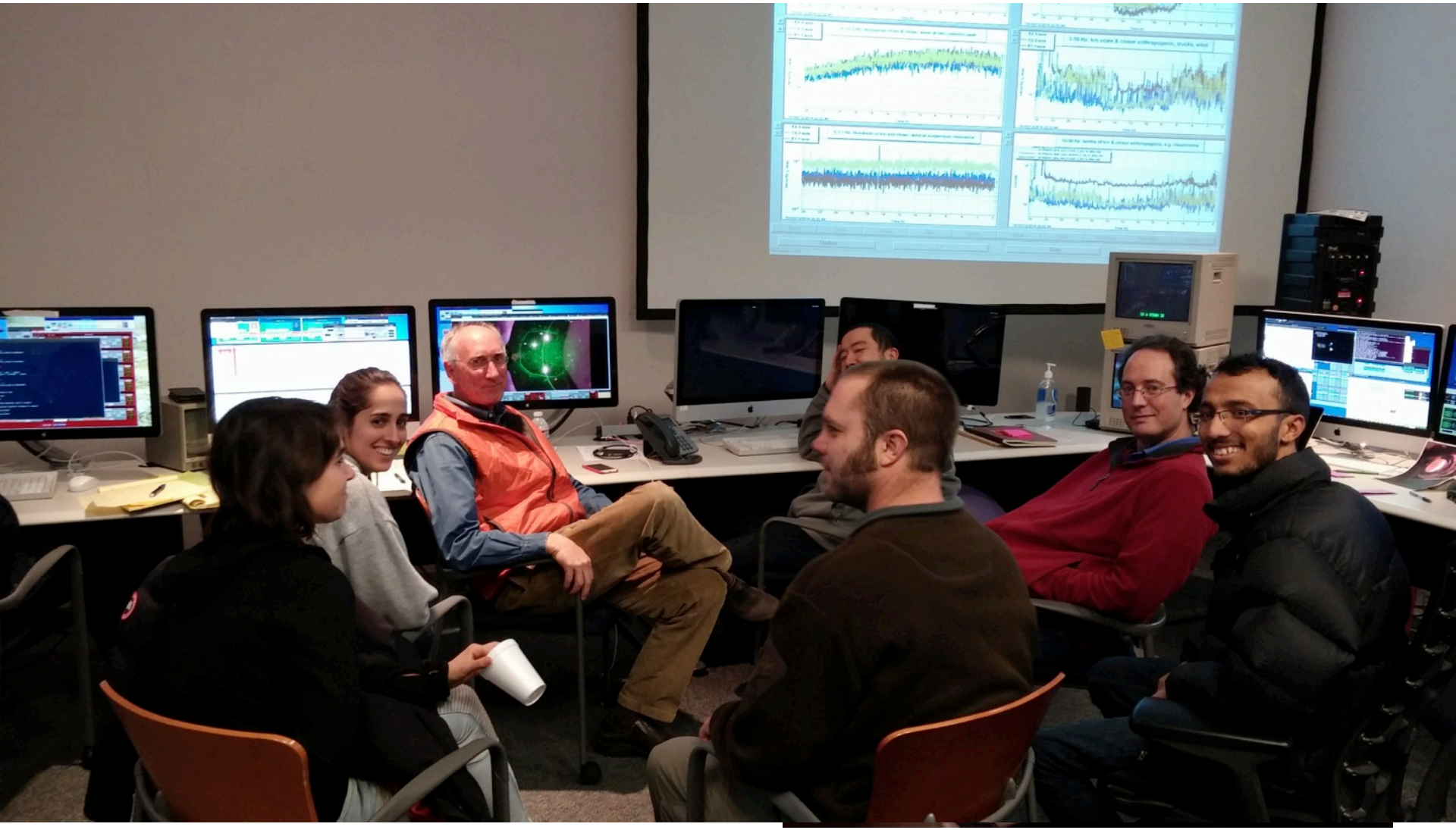
- …losses in the arms much higher than expected (700ppm vs 100ppm, E. King, G1500288)

- Residuals from cleaning (pieces of "first contact" film left on the optic)

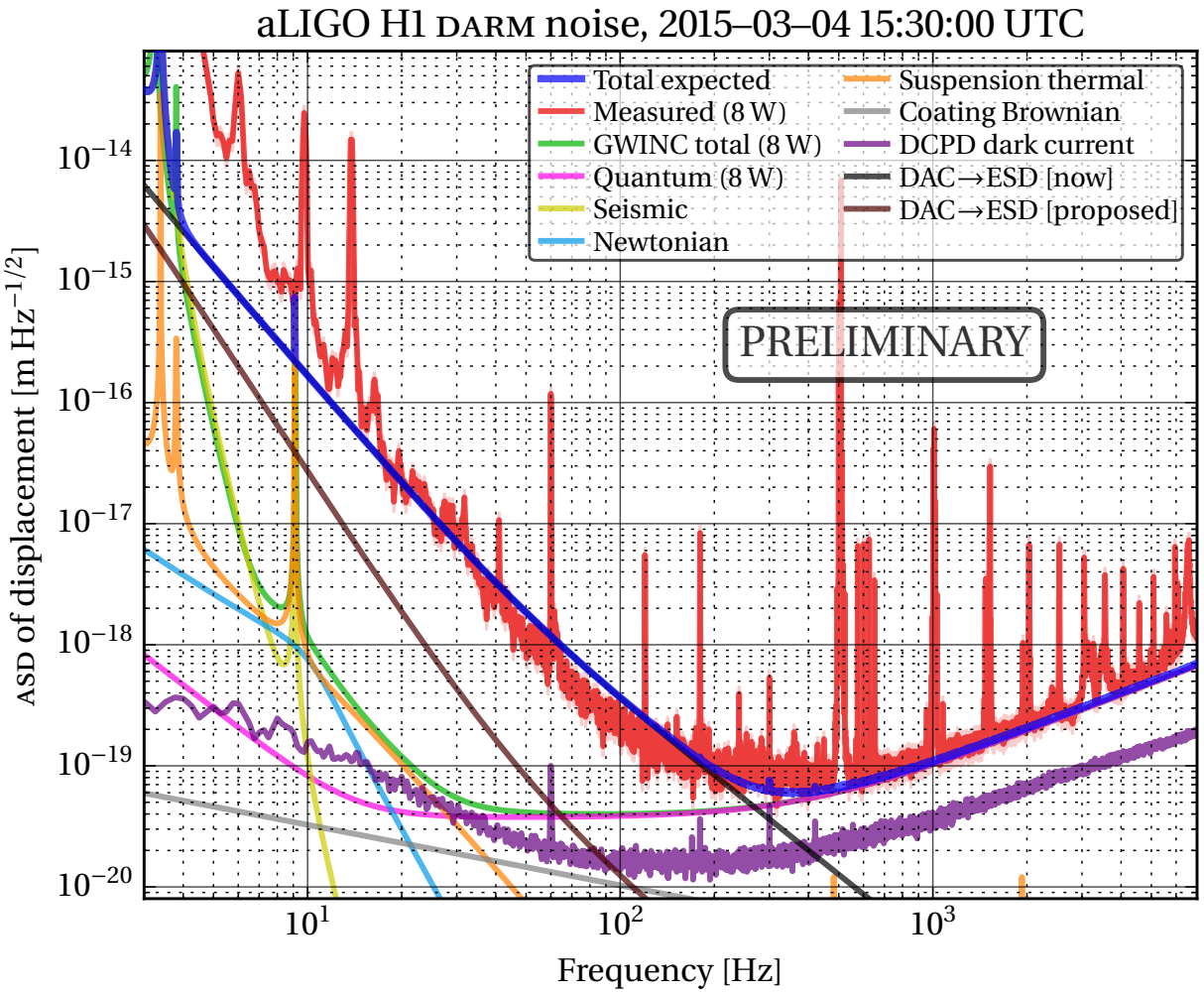
- Losses comparable to L1 after (re)cleaning (~100 pm)



Macroscopic problems are easy to find and fix!



Hanford Sensitivity (E. Hall, **G1500256)**



✧15 Mpc, sensitivity understood

✧Actuator noise limiting low frequency sensitivity (expected)

Current effort on robustness/reliability

H1 ISC Link

stefan.ballmer@LIGO.ORG - posted 03:52, Saturday 14 March 2015 - last comment - 08:11, Saturday 14 March 2015(17267)

Full automation

Sheila, Dan, Chris, Stefan

Tonight we first spent time making the Guardian automation work all the way. After making sure our ASC loops work properly, we added the OMC_LOCK Guardian to ISC_LOCK Guardian control. We had several completely hands-off relocks, taking us all the way to DC readout. Since we often broke the lock trying new things, we got some relocking statistics: from lock-break back to DC-lock is about 15min.

- ✧Locking sequence fully automated, 15 min
- ✧Work on reliable initial alignment strategy
- ✧Global alignment control

Current effort on robustness/reliability

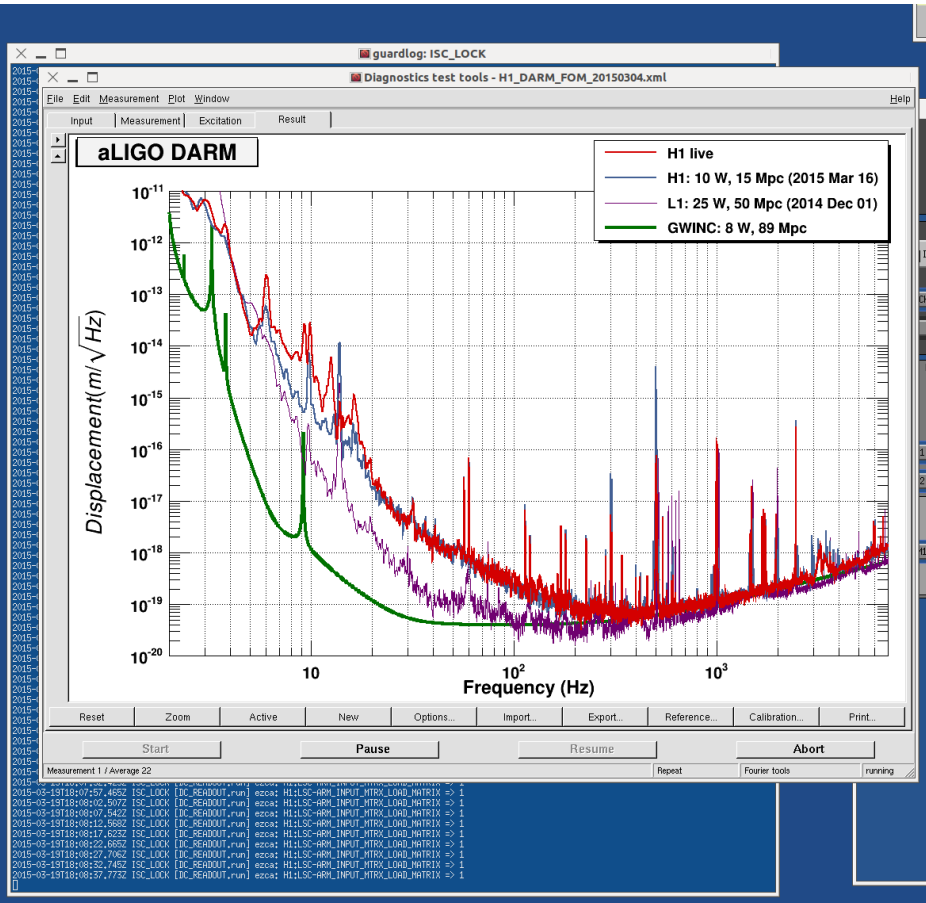
H1 General

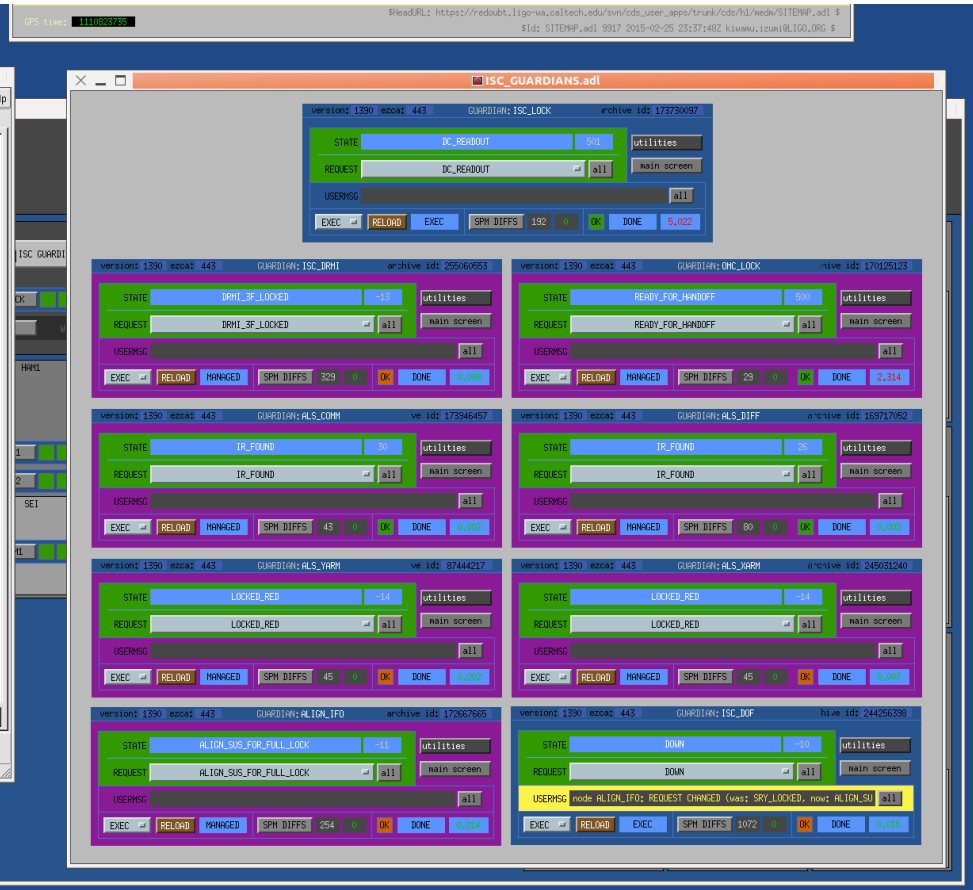
Link

patrick.thomas@LIGO.ORG - posted 11:09, Thursday 19 March 2015 - last comment - 11:10, Thursday 19 March 2015(17354)

Locked on DC readout at ~ 10:55 AM

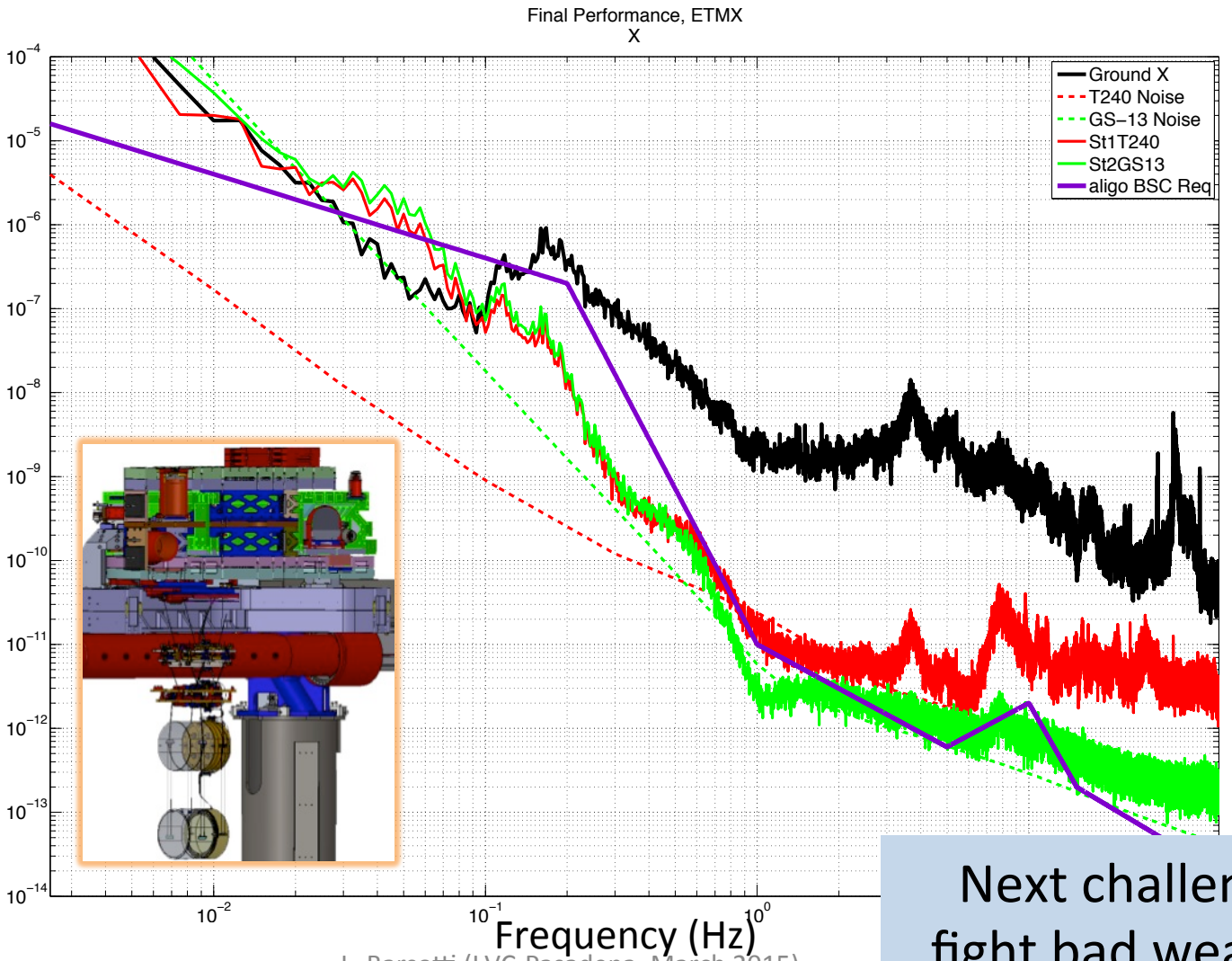
Yeah :)





LHO Seismic Isolation Performance

Displacement
m/sqrt(Hz)



Next challenge:
fight bad weather

L. Barsotti (LVC-Pasadena, March 2015)

➔ What are the most difficult problems we have faced so far?

➔ What are the biggest problem we still have to face to reach design sensitivity and high duty cycle?

Overall, what are the biggest problems we have faced so far?

(source: aligo-ifo and aligo-isc mailing lists)

1) Charging

2) Alignment 2) Green Coating

Overall, what are the biggest problems we have faced so far?

(source: aligo-ifo and aligo-isc mailing lists)

1) Charge

2) Alignment 2) Green Coating

(source: front line commissioners)

1) LLO: Lock of the central part of the interferometer

(because we don't have actuators on the beam splitter optic)

1) LHO: Green coating

2) LLO & LHO: Alignment

What are the biggest problem we still have to face to reach design sensitivity and high duty cycle?

(source: aligo-ifo and aligo-isc mailing lists)

1) "High Power" 1) Scattered light
2) "Upconversion"

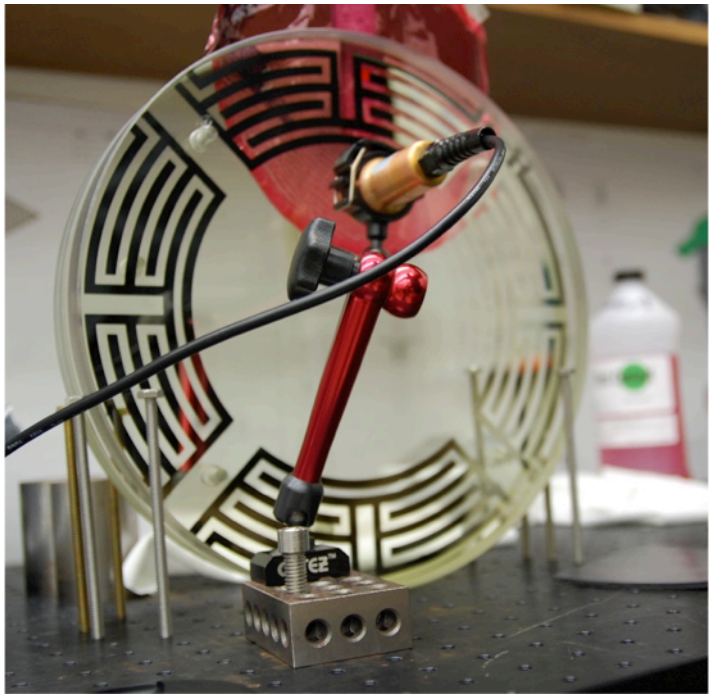
(source: front line commissioners)

1) Scattering
2) Alignment
3) Charge

CHARGE
How about solutions?

- Source of charge identified: first contact (-), ion pumps (+)
- Diagnostic developed to quantify the problem
- L1: charge localized on back of ETMY
- Discharge methods developed, discharge attempts @ LLO
- Other charge-related noise mechanisms might become dominant in the future

R&D @ Caltech and MIT



(Poster, K. Baric G1500383)

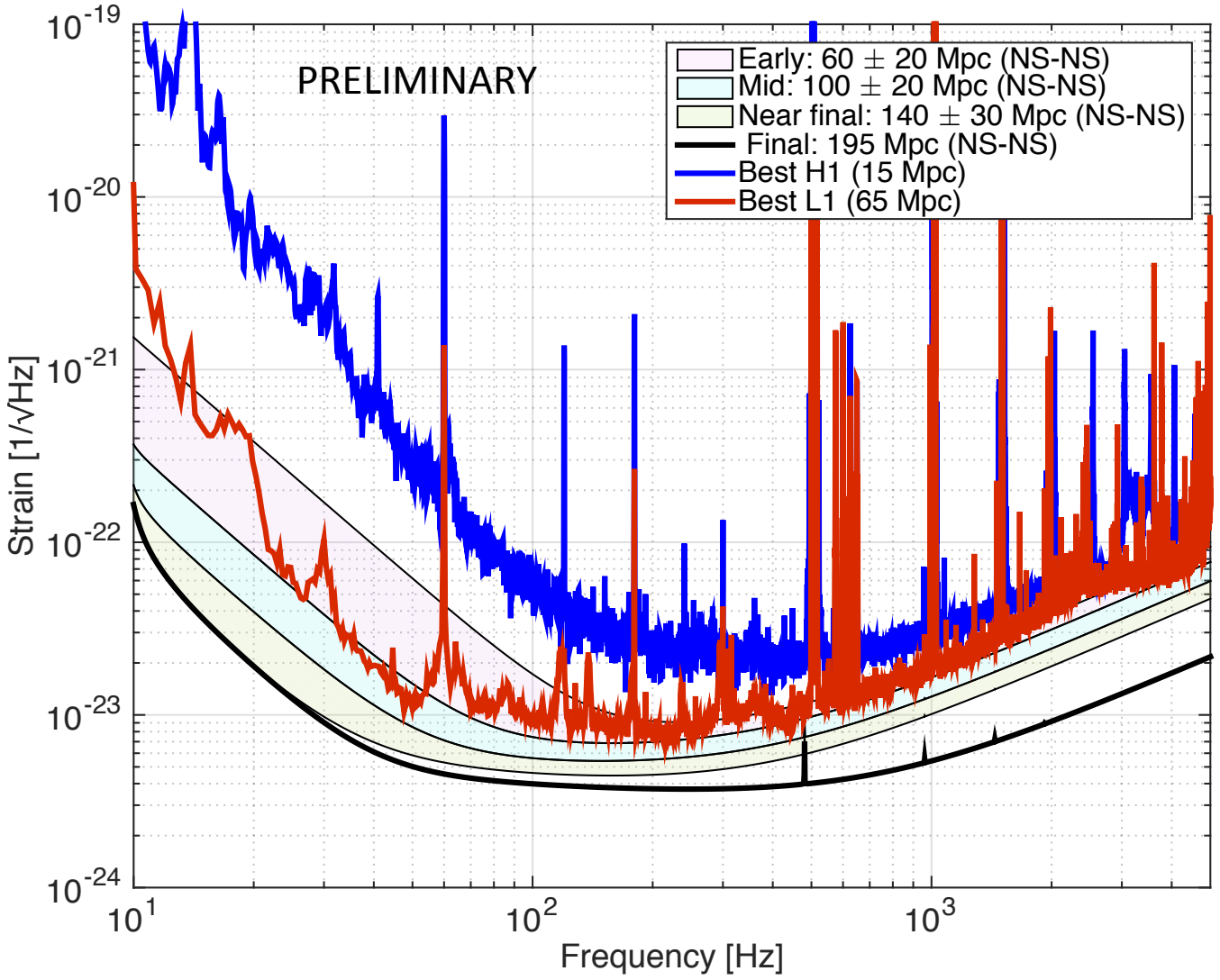
SCATTERED LIGHT
How about solutions?

- ✧On going investigations at LLO (and soon at LHO) to track down scattering sources/ coupling mechanisms
- ✧ “Shroud” for the output mode cleaner

Outlook

- ✧L1 is hunting noises:
  - ✧Main enemies right now: scatter light/charge noise
  - ✧Several possible scenarios depending on outcome
  - ✧For high frequency, power increase is the next step
- ✧H1: good progress, clear path to catch up with L1
- ✧Reliability/automation in parallel at both sites
- ✧Getting ready for Science!

Fast (sometimes incredibly fast) progress, very encouraging results



NEW PRIZEs: best logbook entry! (one for LHO log, one for LLO log)

- Committee: Peter, Lisa, Dave
- Criteria:
  - Relevance and impact
  - Clarity (summary/details format)
  - Data calibrated in physical units
- $150 per prize @ each LVC

LLO log winner:
entry 16444, Den Martynov

L1 ISC Link

denis.martynov@LIGO.ORG - posted 19:24, Monday 19 January 2015 - last comment - 10:58, Tuesday 20 January 2015(16444)

noise budget for 55-60Mpc lock

This alog shows noise budget for the lock stretch from Dec 13. Since then noise improved above 800Hz due to PMC swap (alog 16186, alog 16210), at 256Hz due to perioscope steering mirror mount replacement (alog 16227, alog 16331) and at 10-40Hz (alog 16260). However, we could not get better BNS range yet since PSL output power reduced from 23.5W down to 18W and later to 13.5W after PMC swap.

Attached plots shows noise budgets for DARM, MICH, PRCL and SRCL. During the week we had a several discussions on how can we improve the noise. This is a list of our conclusions:

- DRMI [10 - 40 Hz]. Increase power of POP PD but before try to control DRMI using POP air PD that has factor of ~8 more light compared to invac PD. More power will improve DRMI noise since SRCL is shot noise limited from ~20Hz. MICH noise in the frequency range 10-60Hz probably comes from SRCL due to non-optimal phase rotation of POP 45. Then we plan to switch M3 actuator of small triples to state 3, we used to run in state 1 (lp off, acq off). We also plan to measured RF generator noise coupling.
- Angular controls [5 - 20 Hz]. Estimation in the DARM noise budget is done by taking quad angular control signal, propagating it to angle and multiplying by beam concentering of 4mm (measured using oplevs during power up from 2W to 20W). We plan to tune quad L2 pitch and yaw output matrices to reduce angle to length coupling relative to our beam position.
- Calibration [40 - 70 Hz]. We think that DARM is slightly overestimated (~10-20%) around the loop UGF since we did not account for delay and phase drope due to high frequency violin notches in the OAF calibration block. Our calibration overestimated phase difference between control and error signals by 15^{o} at 60Hz. We have added AI, AA and delay blocks to OAF (alog 16421).
- ESD charge. Noise in the frequency range 40-100Hz is still not clear. ESD discharging might help (alog 16440)
- OMC tuning. We are currently running with 1 whitening stage for OMC trans PDs. Since violin and bounce/roll modes have been low enough lately we can engage second whitening stage and reduce dark noise by ~10 in the frequency range 10-60Hz and factor of ~2 at 100Hz. We might also run at ~20pm DARM offset to increase OMC current. At 15pm we have 28mAmps when input power is 20W. Today I have also noticed that we can increase OMC power by 1% by moving SR2 in pitch by ~30 urad in single bounce configuration. OMC alignment was held using OMs. We also plan to estimate output jitter coupling to DARM.
- Scattering [100Hz]. We can see scattering noise coupling to DARM from HAM6 (alog 16255). We try to investigate how can we damp scattered light inside the chamber.

Non-image files attached to this report

- darm_21W.pdf
- prcl_full_lock.pdf
- mich_full_lock.pdf
- srcl_full_lock.pdf

Comments related to this report

denis.martynov@LIGO.ORG - 10:58, Tuesday 20 January 2015 (16453) Link

Attached are .fig files for the noise budget plots

Non-image files attached to this comment

- DARM_NoiseBudget.fig
- MICH_NoiseBudget.fig
- PRCL_NoiseBudget.fig
- SRCL_NoiseBudget.fig

LHO log winner:
entry 16569, Evan Hall
(+ Sheila Dwyer and Alexa Staley)

H1 ISC Link

evan.hall@LIGO.ORG - posted 05:25, Monday 09 February 2015 - last comment - 13:38, Monday 09 February 2015(16569)

1 hour lock on analog CARM, 4 kHz bandwidth

Sheila, Alexa, Evan

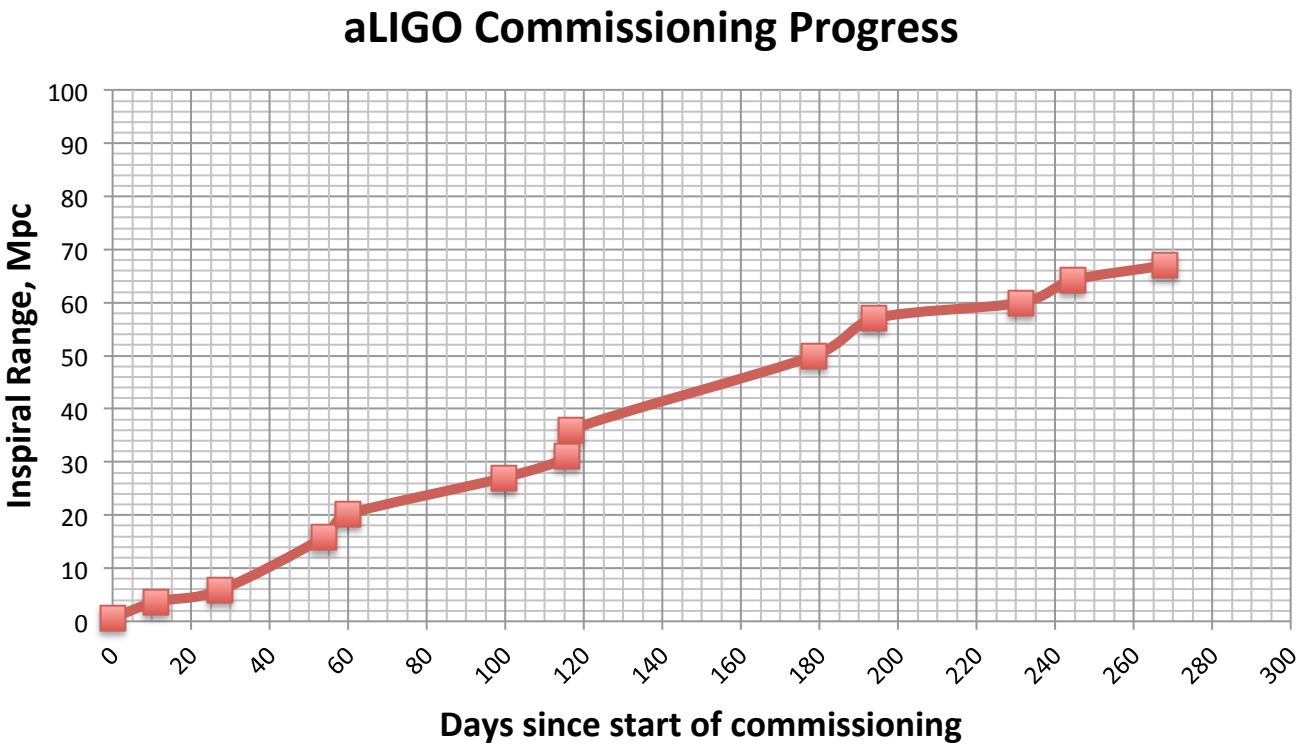
Summary

We have transitoned CARM from digital normalized REFLAIR9I to analog REFLAIR9I, with a 4 kHz bandwidth and 50 degrees of phase. An OLTF is attached [the last data point is spurious, so ignore it]. This lock started at about 2015-02-09 12:24:00 UTC. **We are leaving the IFO locked.**

There is plenty of phase to push the bandwidth higher, but we have encountered large offsets induced by switching on the common-mode and summing-node boards.

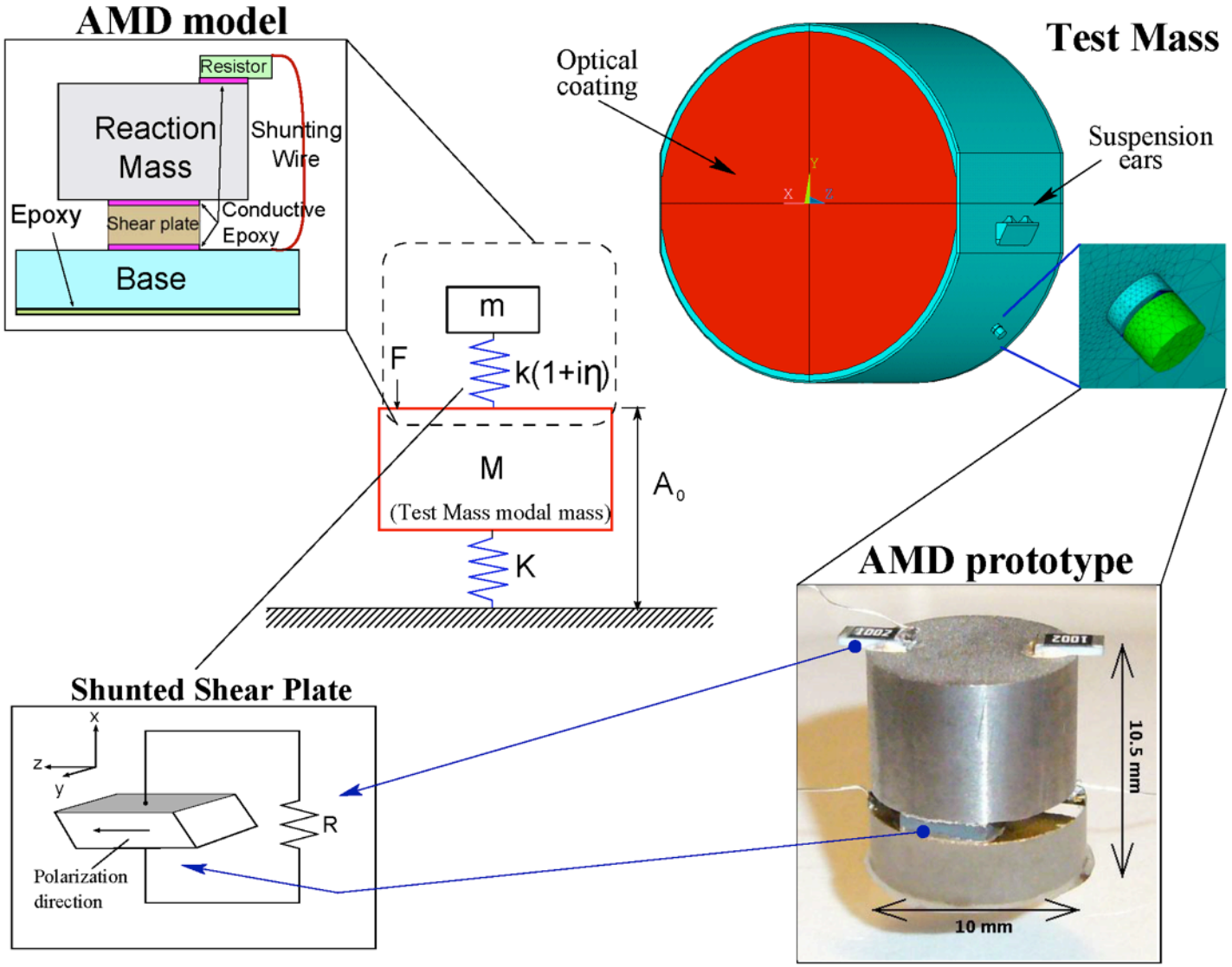
We can also improve the low-frequency fluctuations of the CARM error signal by introducing an integrator somewhere; we need more dc gain.

Keep climbing..

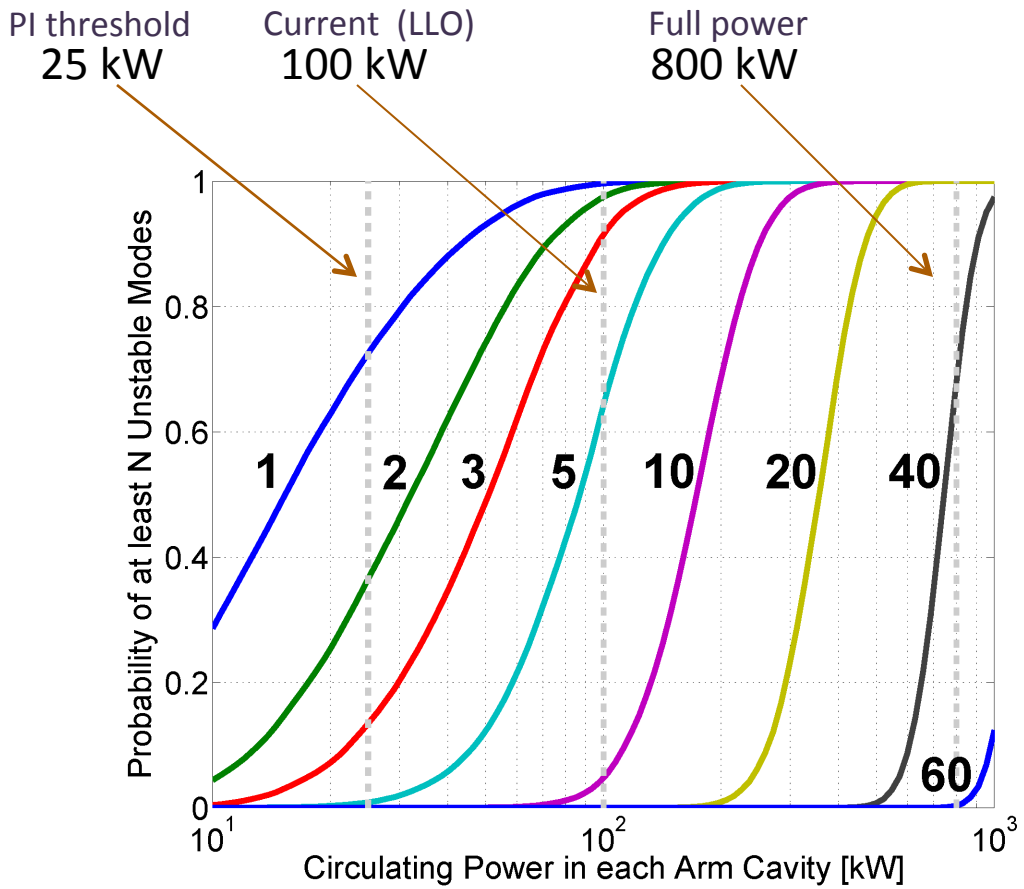


D. Shoemaker G1500192

Acoustic Mode Damper



Forecast for the future



More than 40 modes needed to be damped at 800 kW

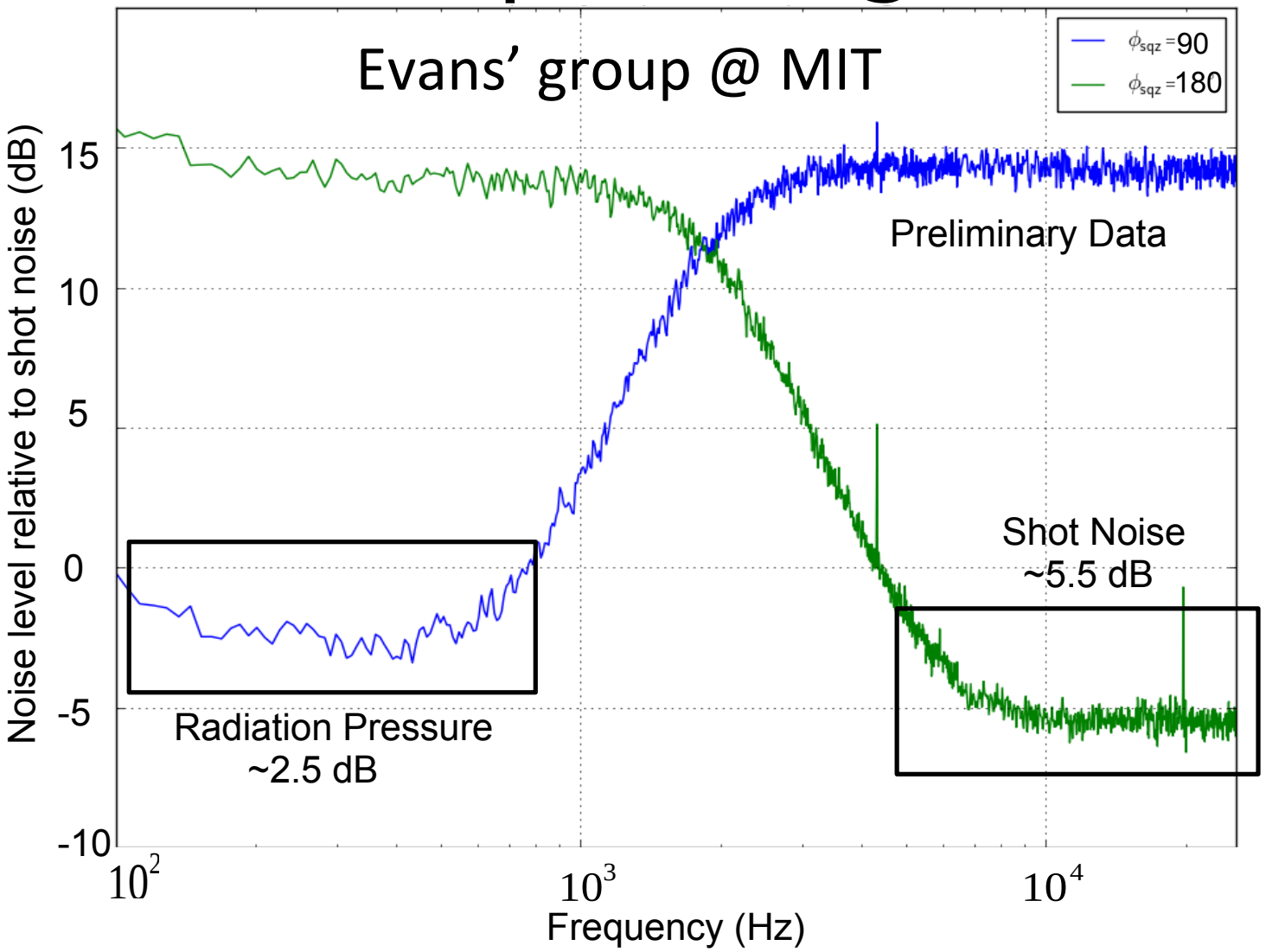
Sources of the charge

R. Weiss, G1500264

- Application and removal of "First Contact"
  - Initial removal leaves $\sigma \sim -10^{-9}$ coulombs/cm^2 on the glass
    - Remove charge by flooding area with low density neutral plasma (Top-Gun) and a sampling electrometer sensitive to $\sigma \sim 10^{-12}$ coulombs/cm^2 (initially 30 x poorer sensitivity).
    - Residual charge may well be due to incomplete neutralization and incomplete removal of the film
- Emission by ion pumps
  - Fluctuating surface charge densities $\sigma \sim +10^{-12}$ coulombs/cm^2 with ~10 hour exposure to the pumps.
  - No ion pumps in direct line of sight to test masses, most likely uv and xuv (10 to 200 eV photons) being reflected by tube walls cause photo emission at the test mass
  - Surface potential limited by maximum photon energy to several 100 volts

Frequency Dependent Squeezing

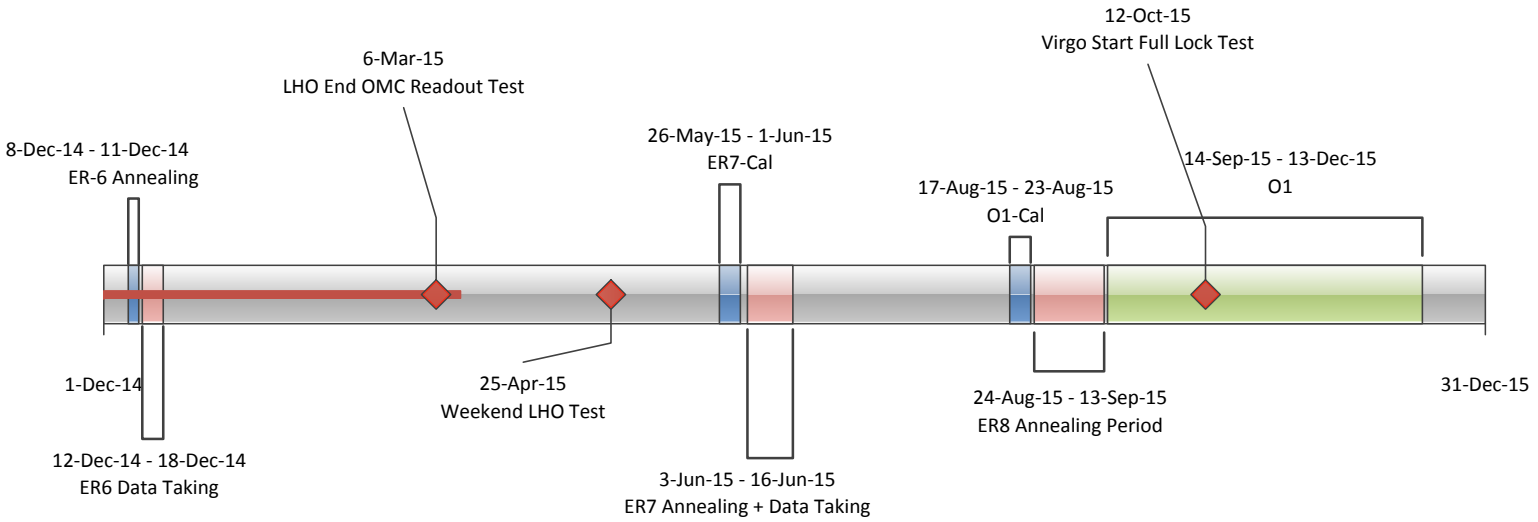
E. Oelker, G1500337



Path to O1

Working Timeline to First Observing Run
(G1301309; Final 12-Mar-15)

LIGO-G1301309



- **ER7: beginning of June**:
  - in less than 3 months
  - length/scope similar to ER6 on BOTH L1 & H1

- **ER8: end of August**, as preparation for O1

- **O1 starting mid-September**:
  - up to 3 months of data taking