Automating Interferometer Control and Noise Regression

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1: Automating Interferometer Control

Signal Blending

- Lock acquisition needs (multiple) handoffs between different signals for same DoF in different states and regimes
- In general, we often have multiple signals for single physical quantity
  - Common arm length
  - DRMI lengths (1F/3F)
  - Optic angular position
- Why not blend these in some way to reduce uncertainty?

Lock Acquisition Strategies

- "Guided Lock": Estimate mirror velocity from observed fringe, apply an impulse to counteract that momentum

- "LIGO1" multi-step: update sensing matrix at intermediate unstable states, based on calculations and simulations of the interferometer response

- Virgo "Variable Finesse": acquire in decoupled state, slowly transition to final sensing and operating point

Lock Acquisition Strategies

- aLIGO: Decoupled green light control + CARM offset reduction. Handoffs triggered at certain CARM offsets.
- Izumi et al “Self Locking”: “Automatic” blending behavior of ALS and PDH due to cavity build up.

A New Approach

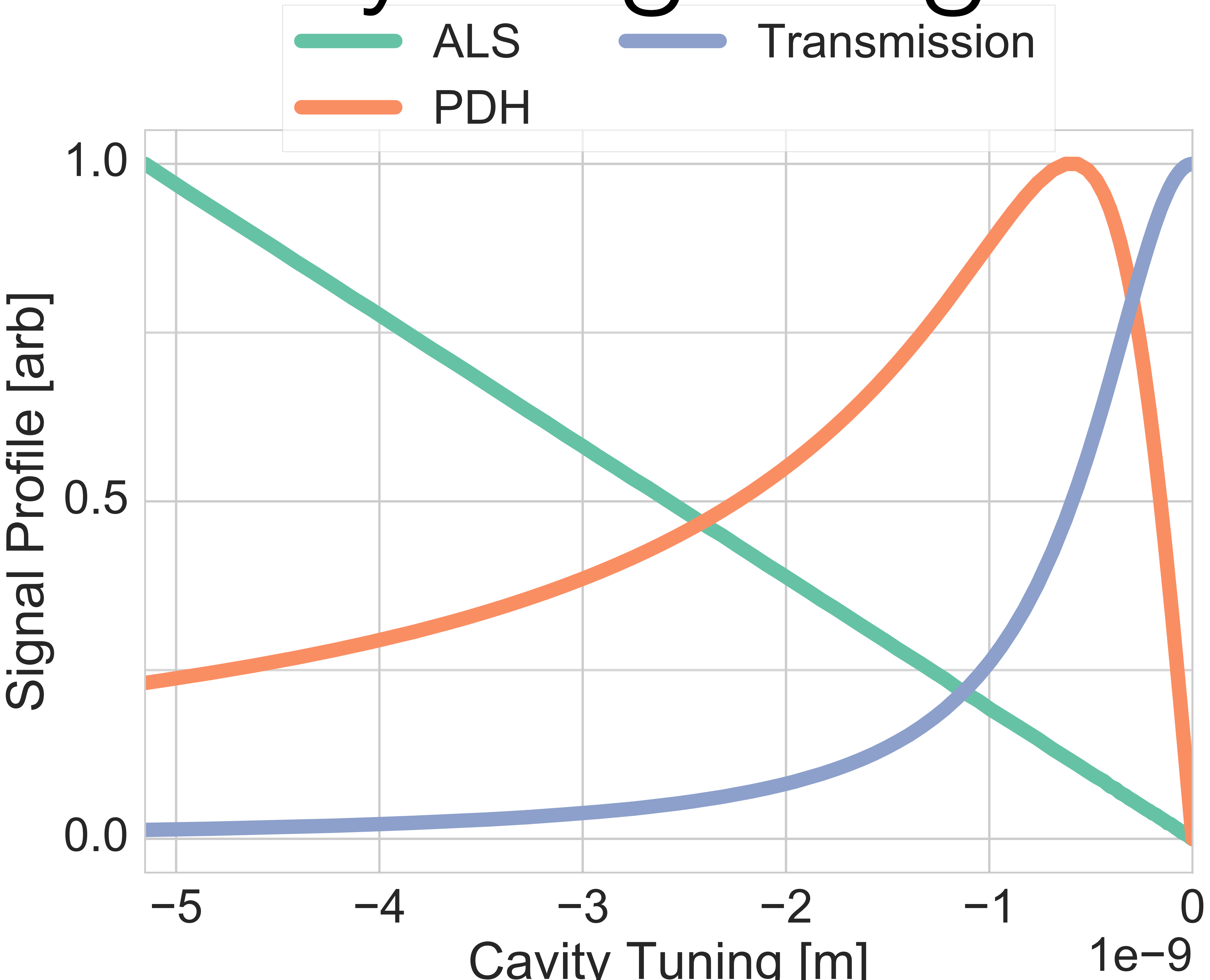
Try to minimize a-priori characterization:

- Continuously demodulate each available signal to determine slopes and monitor noise levels
- Weigh each signal by relative incoherent noise
- Take small offset steps towards desired operating point, recalculate input matrix coefficients
- "**C**ombined **E**rror **S**ignal by **A**utomatic **R**egression"

A New Approach

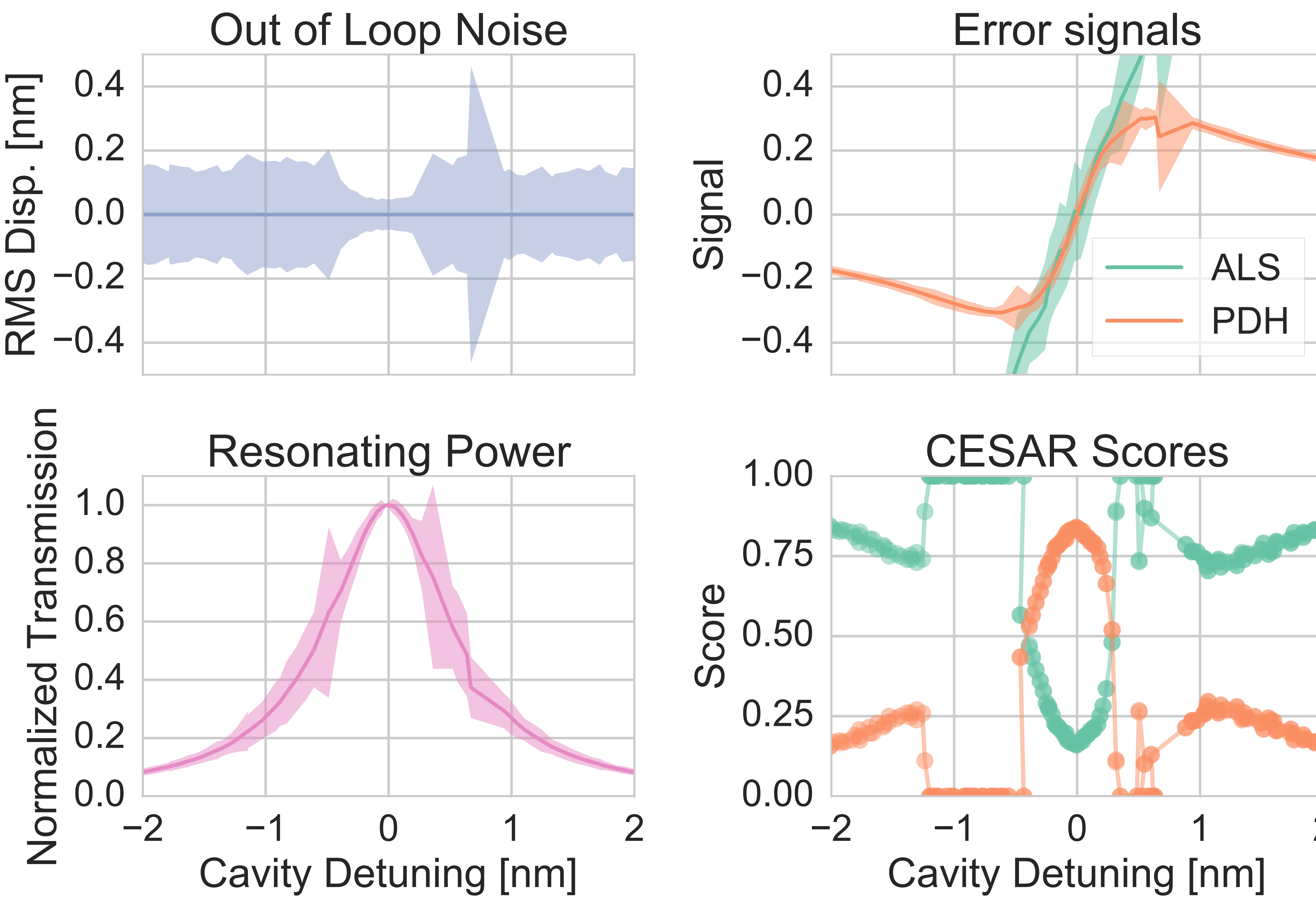
- Single 40m arm cavity as testbed, can iterate quickly, three signals usable for testing (ALS, PDH, DC Transmission)
- First tested on “realistic” E2E time domain simulation to see if the approach has any merit
- Test on actual hardware with same weighting code

3 cavity length signals

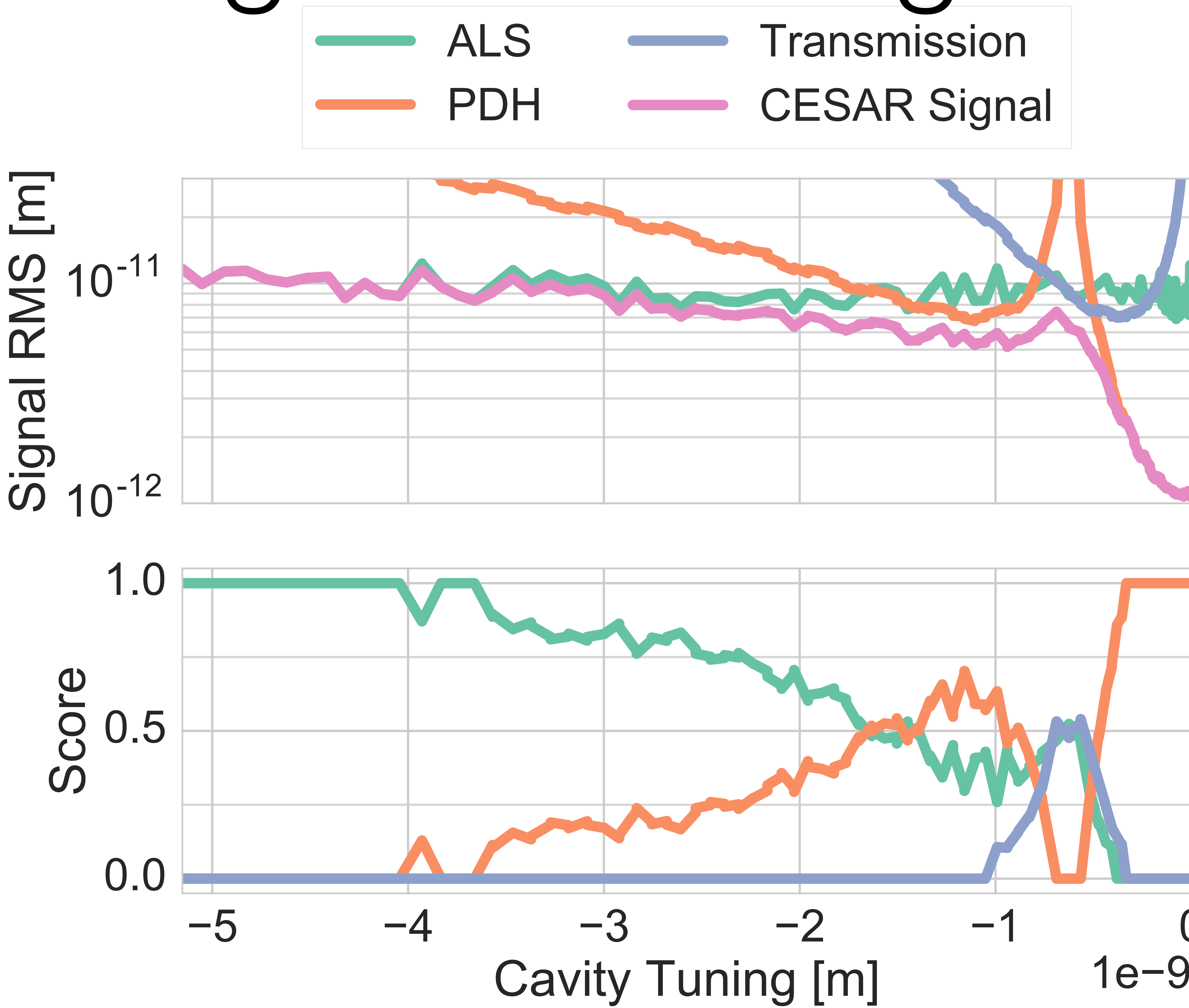


Two signal Simulation

Shaded Areas = RMS fluctuations



3 signal blending at 40m



Lessons Learned

Benefits:

- Less a priori knowledge needed than previous strategies
- Blending, rather then discrete handoffs, reduces noise

Issues:

- Slow, no memory
- No frequency dependent blending (yet)
- Can become unstable around sensing singularities

aLIGO Prospects

- This can provide a “push-button” approach to transitioning between two signals at a given operating point.
- DRMI signals don’t have frequency dependent mismatch, so this approach could automate the 1F/3F handoffs even when the signal chains change
- If the ETM replacement improves the ALS performance enough, there could be a straightforward ramp to PDH CARM control

2: Noise Regression

Noise Regression

- “Non-fundamental” noise couplings into the interferometer are inevitable.
    - Other cavity lengths, angular control noise, newtonian noise, etc.
- Witnessing these influences in other sensors helps us mitigate them.
- However, couplings change over time or mitigations may be imperfect

Noise Regression

- Why not do some post-processing to remove whatever is left over in the interferometer output?

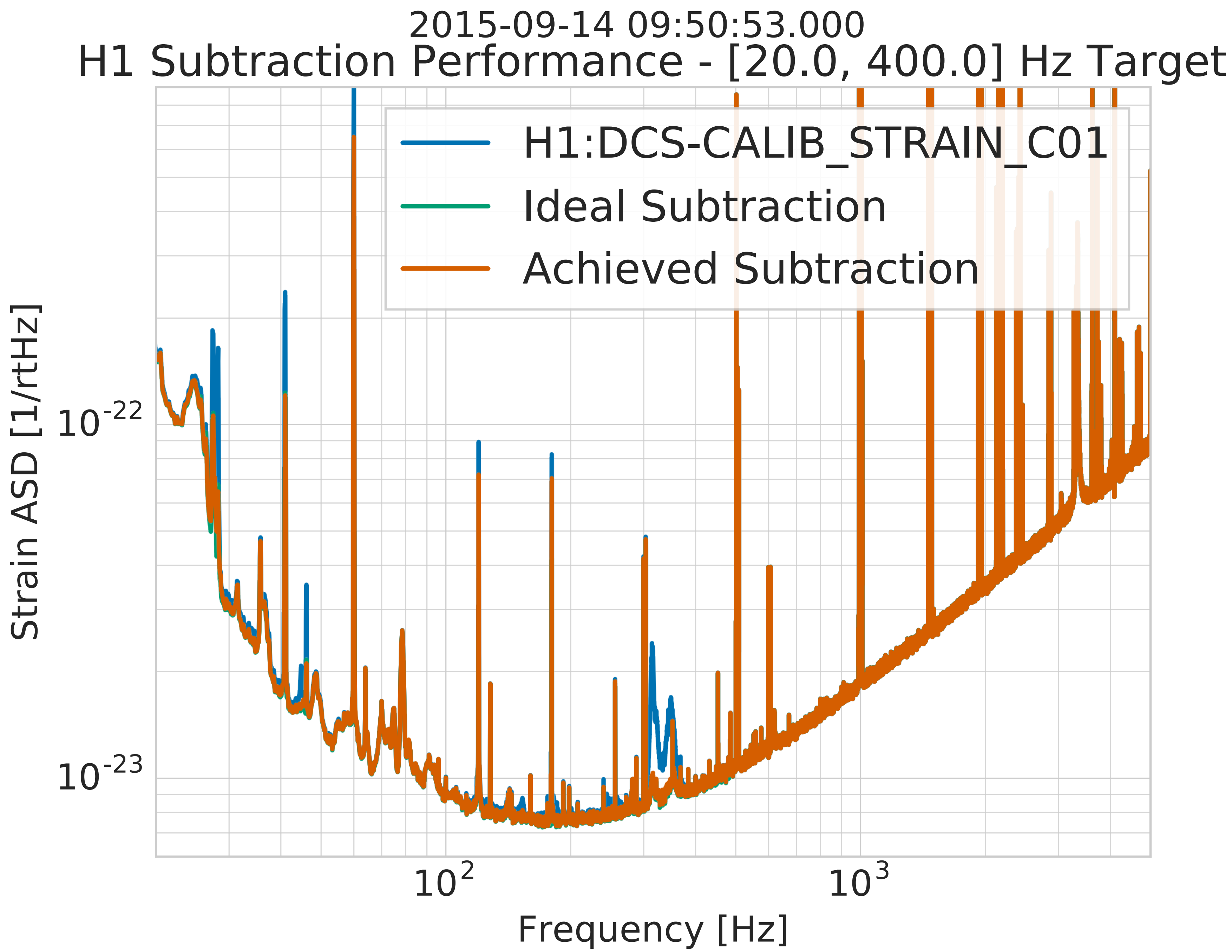
- Not a new idea, but takes time, tuning, and validation.

- Put together some tools to automate the evaluation of hundreds of auxiliary data streams in a coherent way, searching for noise reduction potential.

Noise during GW150914

Subtracted signals:

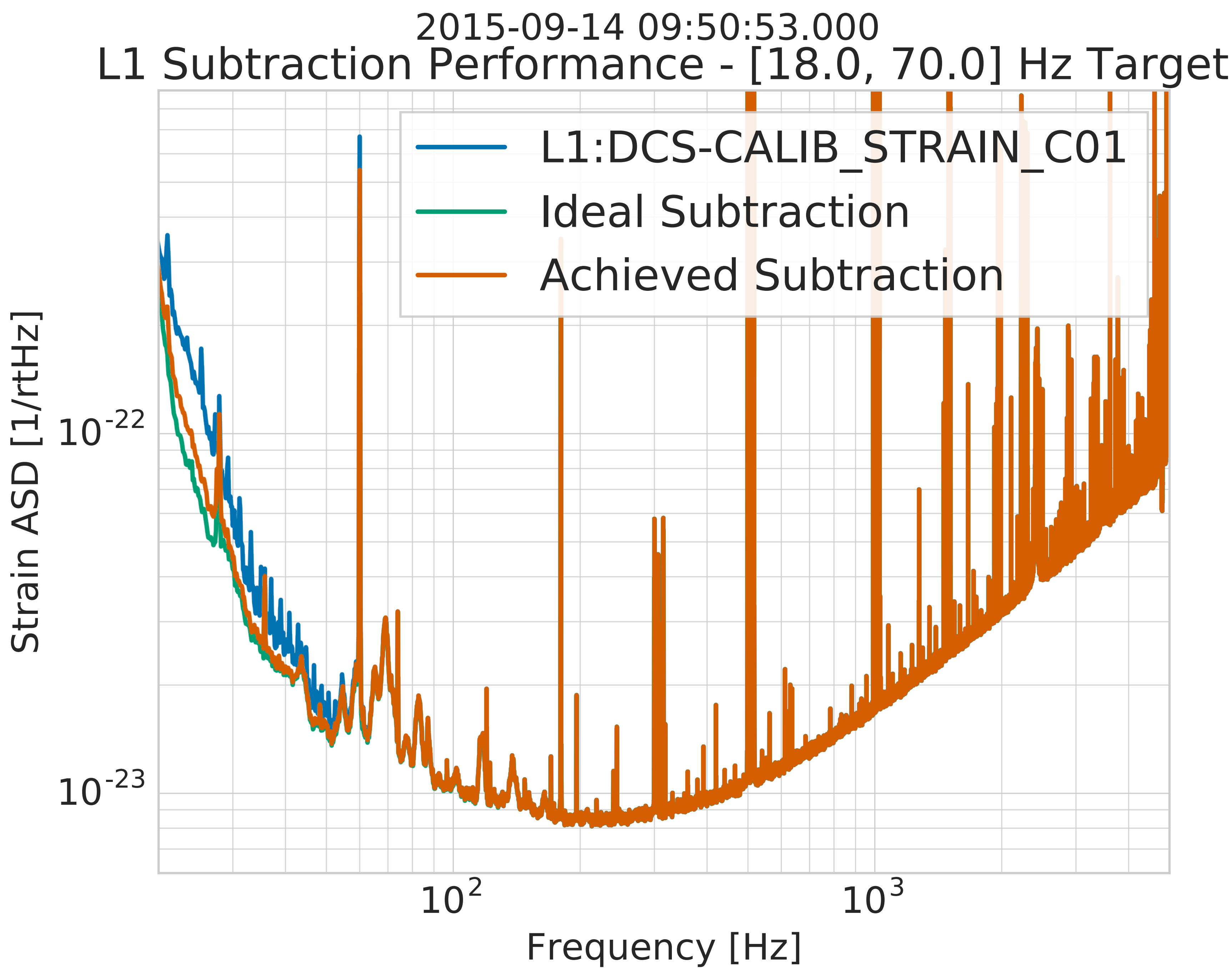
- Calibration Lines
- PSL periscope jitter
- DRMI cavity length



Noise during GW150914

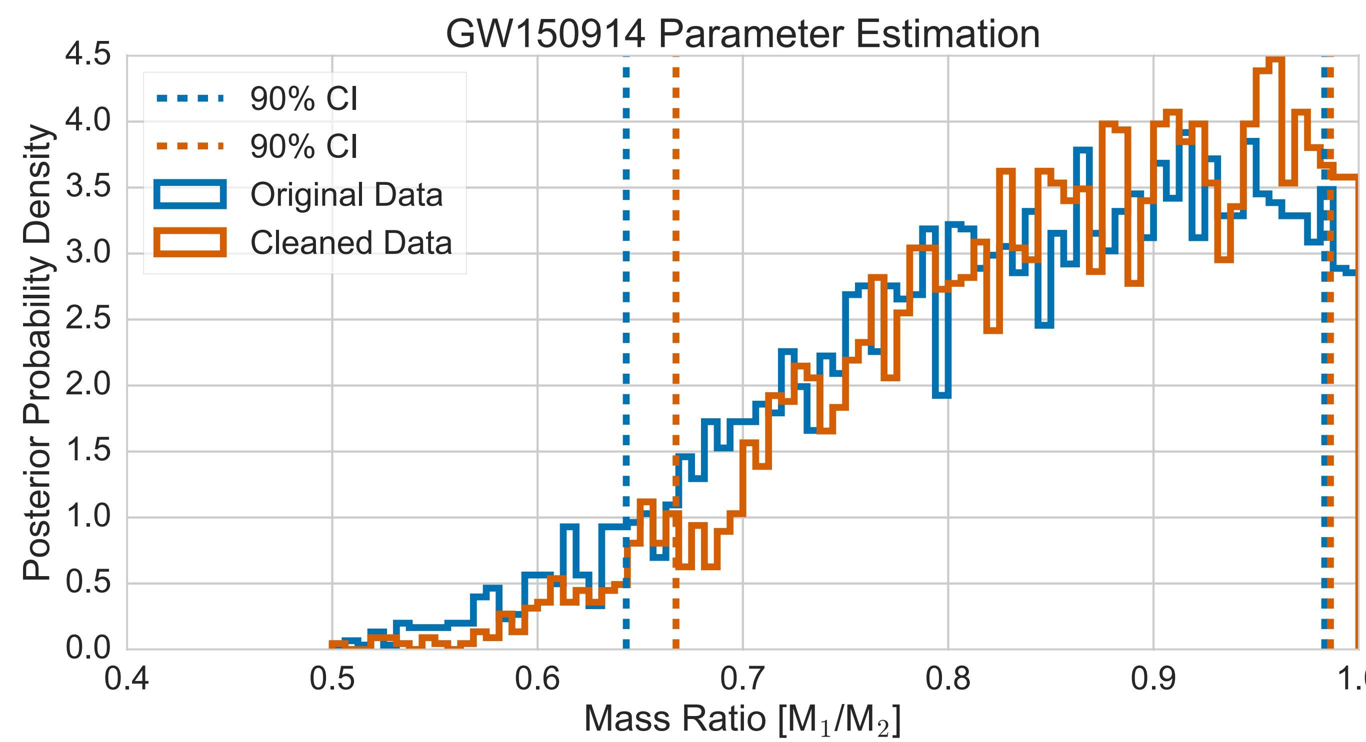
Subtracted signals:

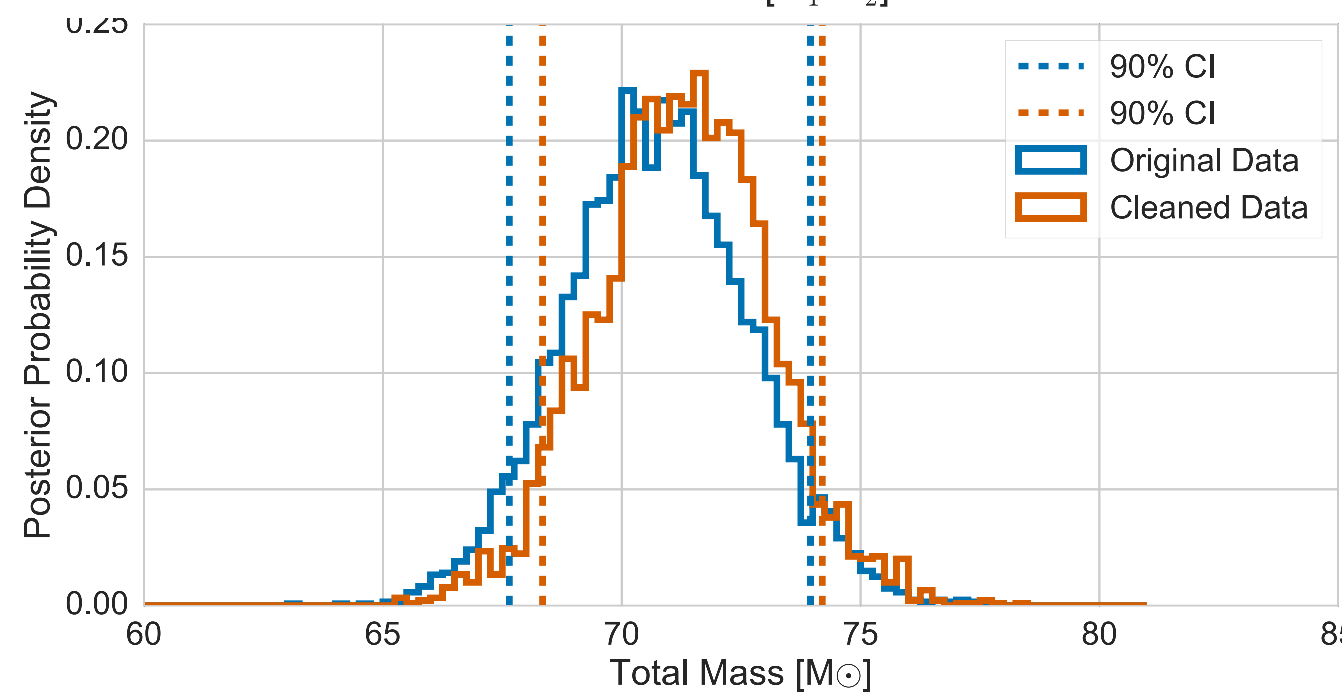
- Calibration lines
- Test Mass angular controls
- DRMI cavity length
- ISI Seismometer signals
- Y End Tiltmeter



Parameter Estimation

Improves the network SNR of GW150914 by **6%** and the width of the mass parameter 90% confidence intervals by about **7%.**





EQ & Rory S. (Caltech)

Just scratching the surface

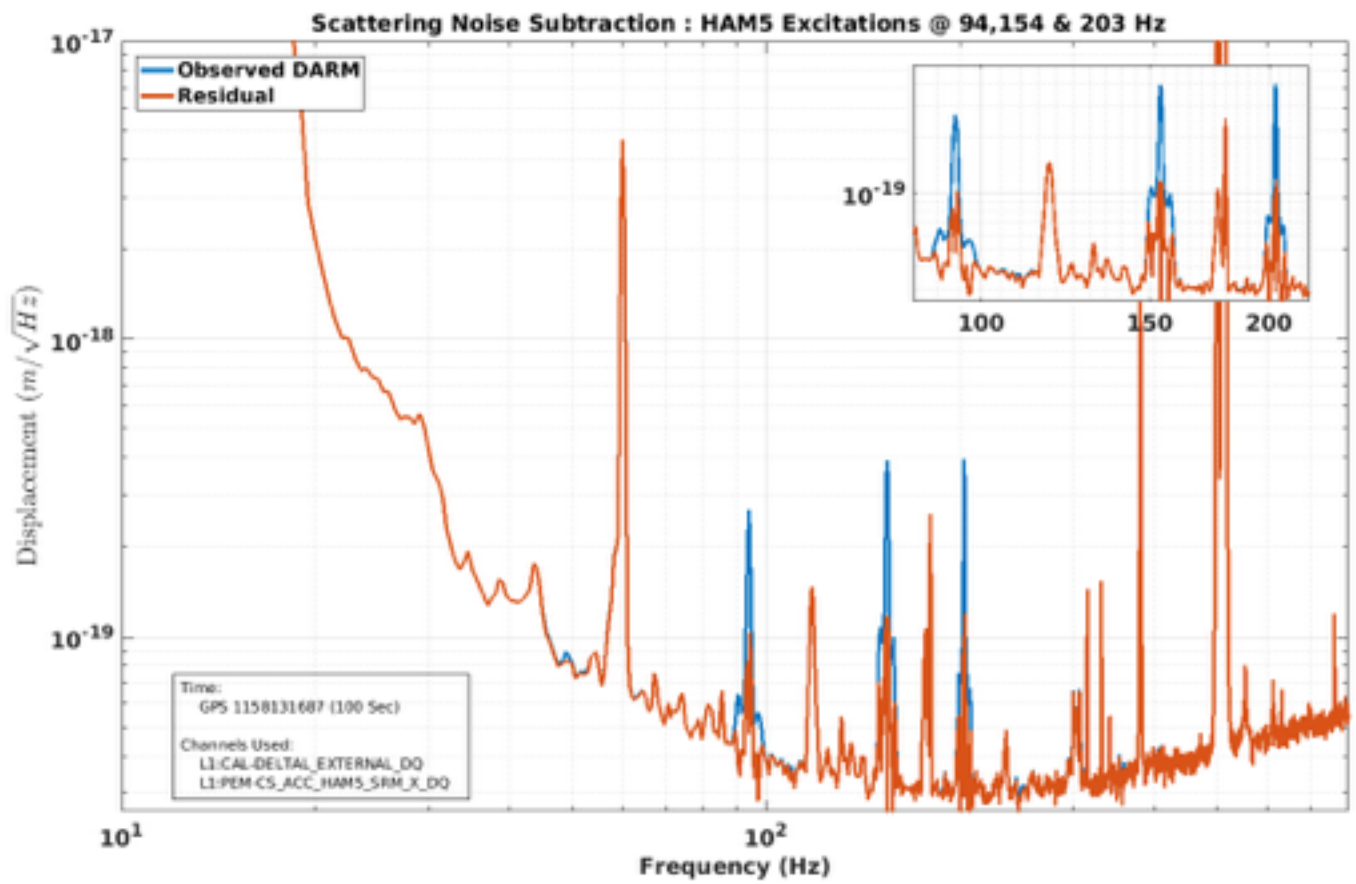
- Really, this started with hopes to diagnose the excess low frequency noise as some form of **bilinear** coupling.
    - e.g. residual beam spot motion and mirror angular motion
- Targeted bilinear search didn’t turn up much, but there is now a team of people thinking about general methods for **nonlinear** noise regression

Scattered Light

$$n(t) \propto A(t)(\alpha B(t) + \phi_0)$$

Light scatters out of cavity, hits something **moving at acoustic frequencies**, and back into cavity. The amount of light scattered is modulated by some **slow cavity motion**.

Some success has been had in creating a “pseudo-channel” that predicts the noise from environmental and suspension data.

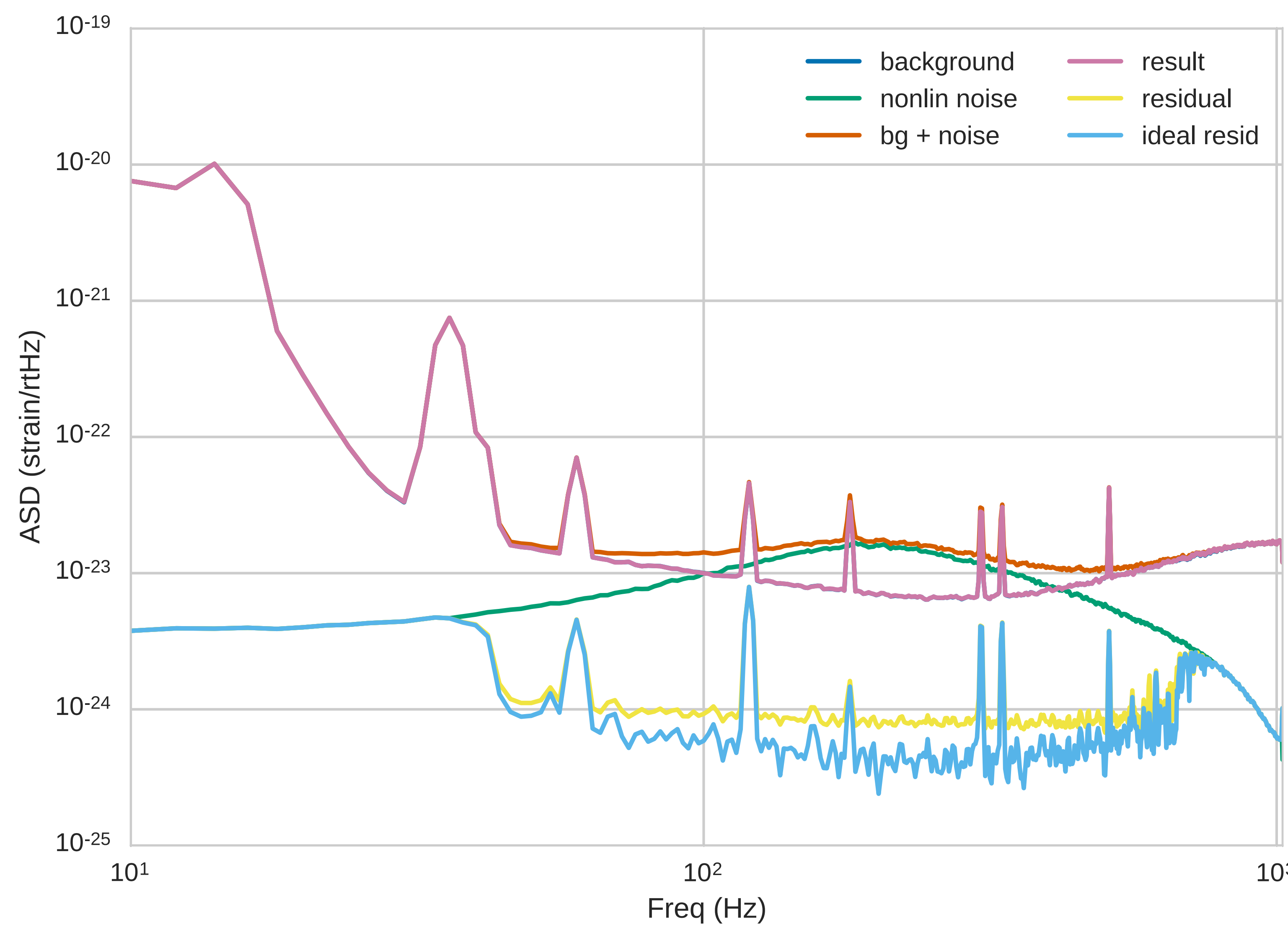


Nikhil M. (IUCAA)
& Gautam V. (Caltech)

Generalized Models

What if we don't know the functional form or frequency dependence?

- Symbolic regression via "Genetic Programming"
- Fit Fourier series to scaled witness signals
- Use neural networks as nonlinear function approximations



Lydia N. (Caltech)

Prospects

- It is naturally always preferred to eliminate noise at the source, but we can and should do everything we can to squeeze out the best possible signals.
- Linear couplings can be quickly identified and subtracted via familiar techniques
- We will continue developing tools for nonlinear diagnosis and regression