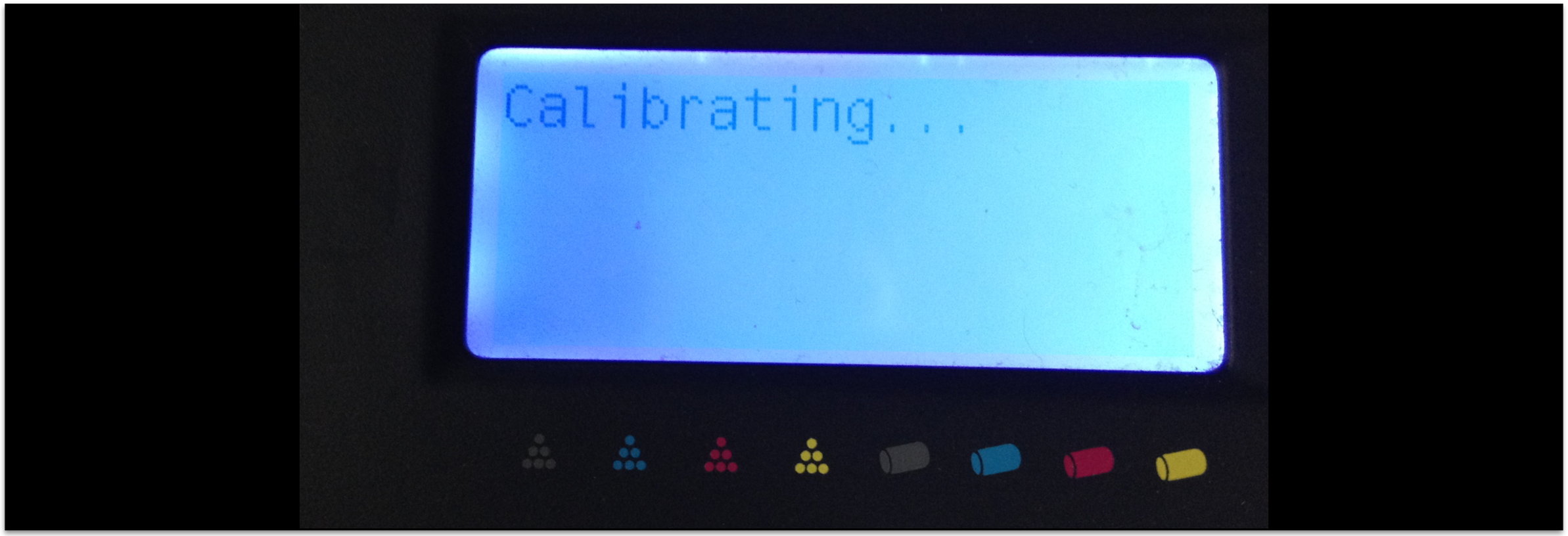
Calibration

of the Advanced LIGO detectors



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ON BEHALF OF THE ADVANCED LIGO CALIBRATION GROUP

Open Data Workshop, March 25, 2018
LIGO Document G1800648

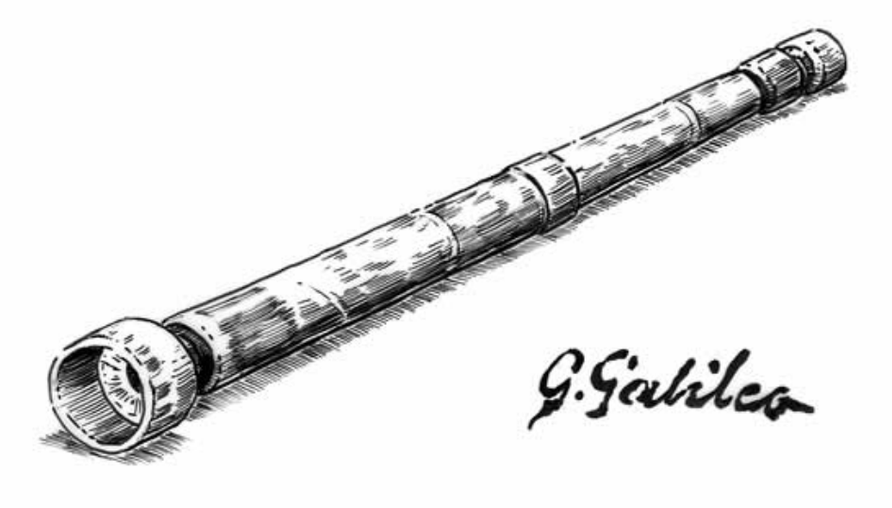
Outline of This Talk

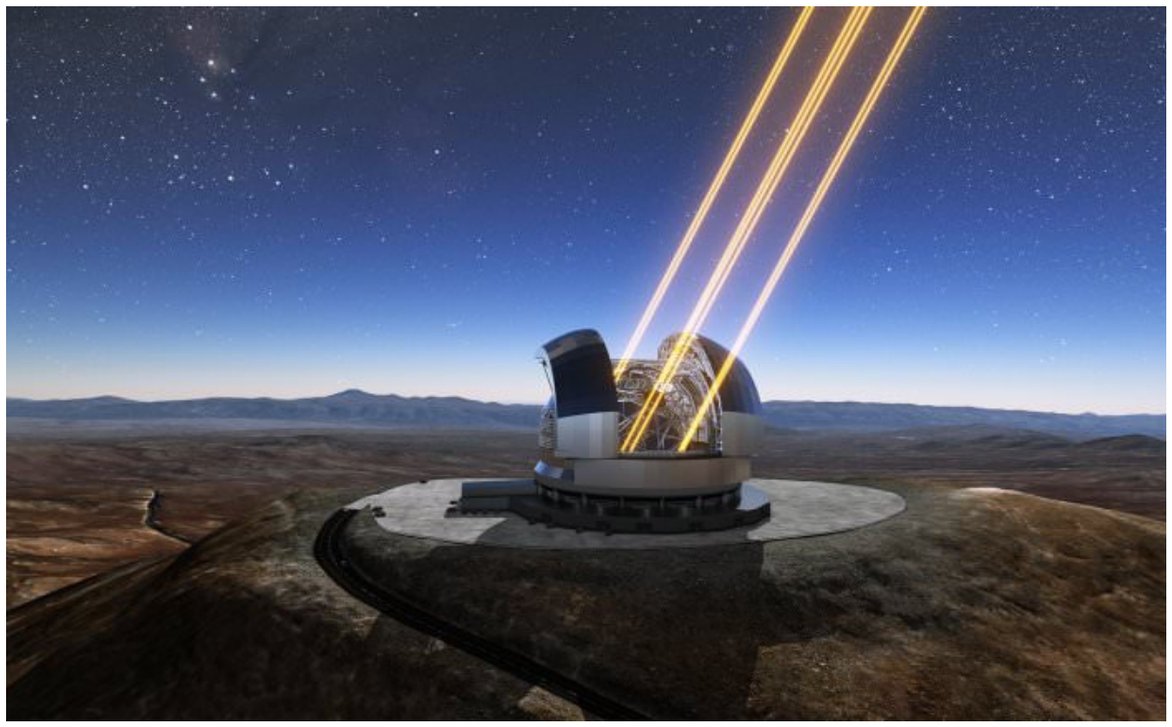
- Sketch a cartoon picture of Advanced LIGO calibration
- Overview of strain calibration process
- Tracking and compensating for slow instrument changes in real-time
- Impact of these changes on astronomy

Caveats

- Advanced LIGO instruments are **complicated**: calibration can seem like a Rube Goldberg scheme
- I am a data analyst, not a (mechanical) engineer

Familiar Example: Optical Telescopes





main idea is to calibrate brightness (photometry)

this can be done using a catalogue of standard astronomical sources

modern telescopes use e.g. adaptive optics, but the idea is the same

Ground-based GW Observatories

Laser **I**nterferometer **G**ravitational-wave **O**bservatory

L1 H1

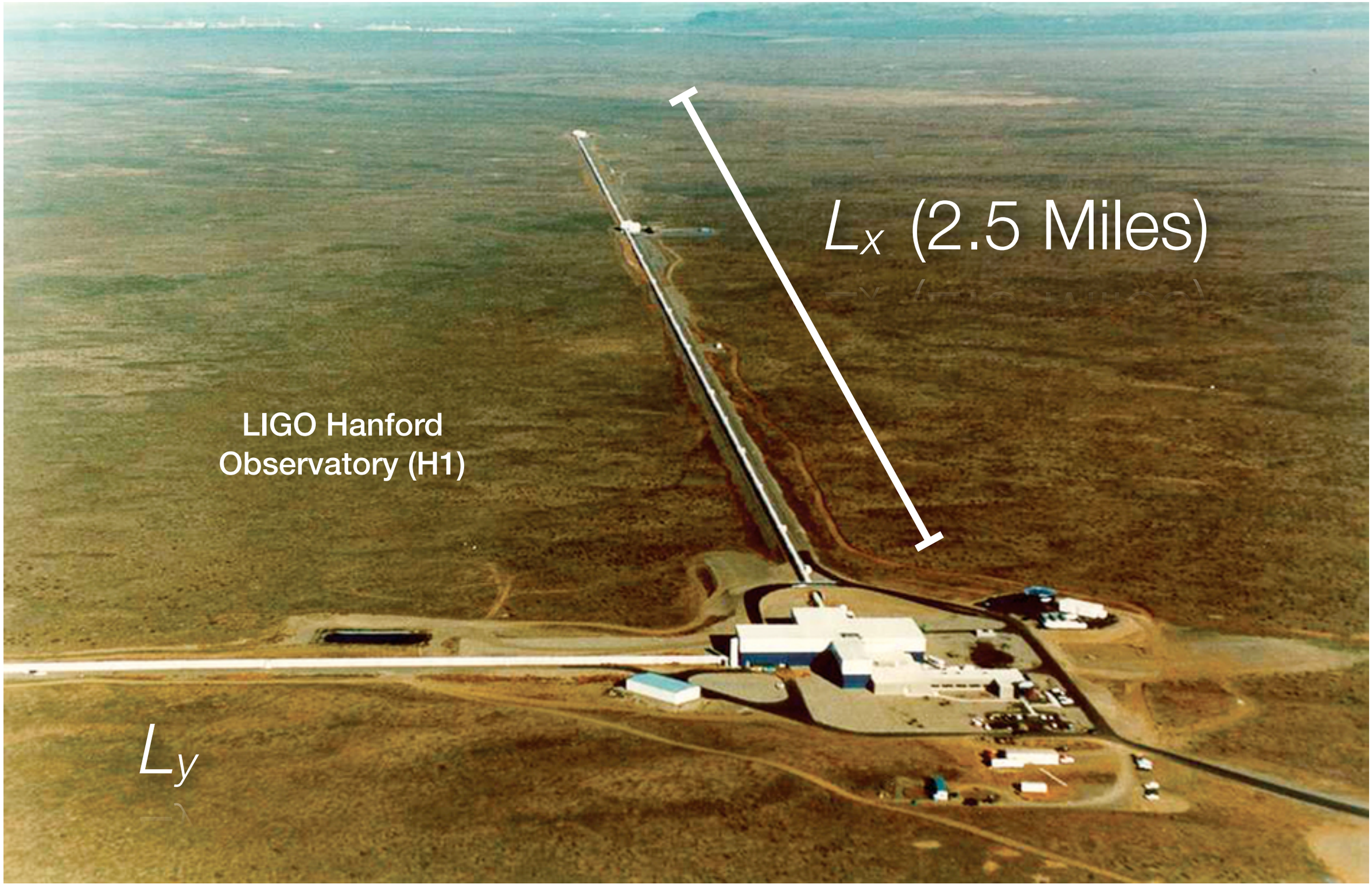
LIGO

+ Virgo (V1; Italy),
GEO (Germany),
KAGRA (Japan)

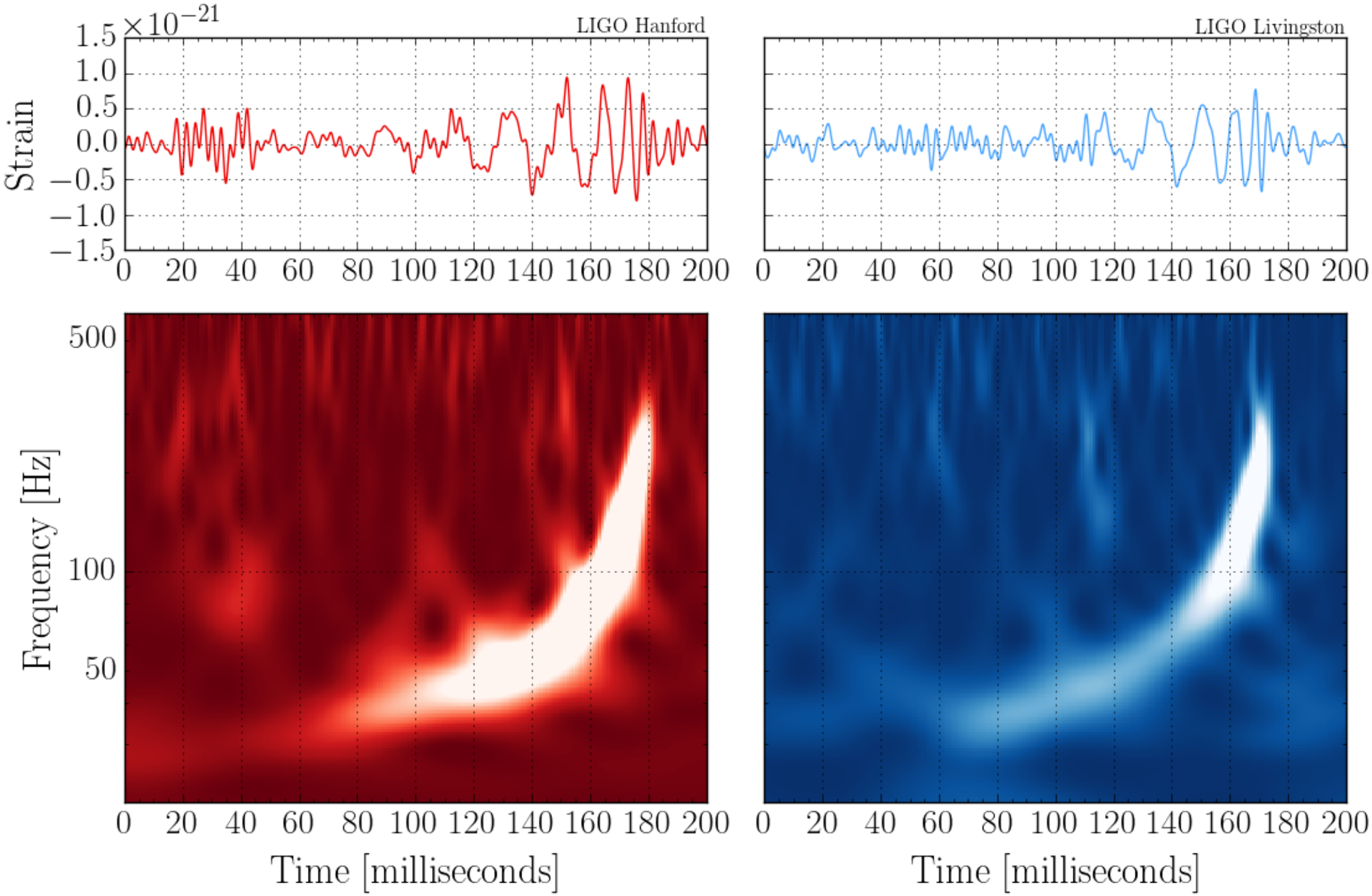
THIS TALK FOCUSES ON LIGO

here we calibrate **strain**:

$$h(t) = \frac{\delta L_x(t) - \delta L_y(t)}{L}$$

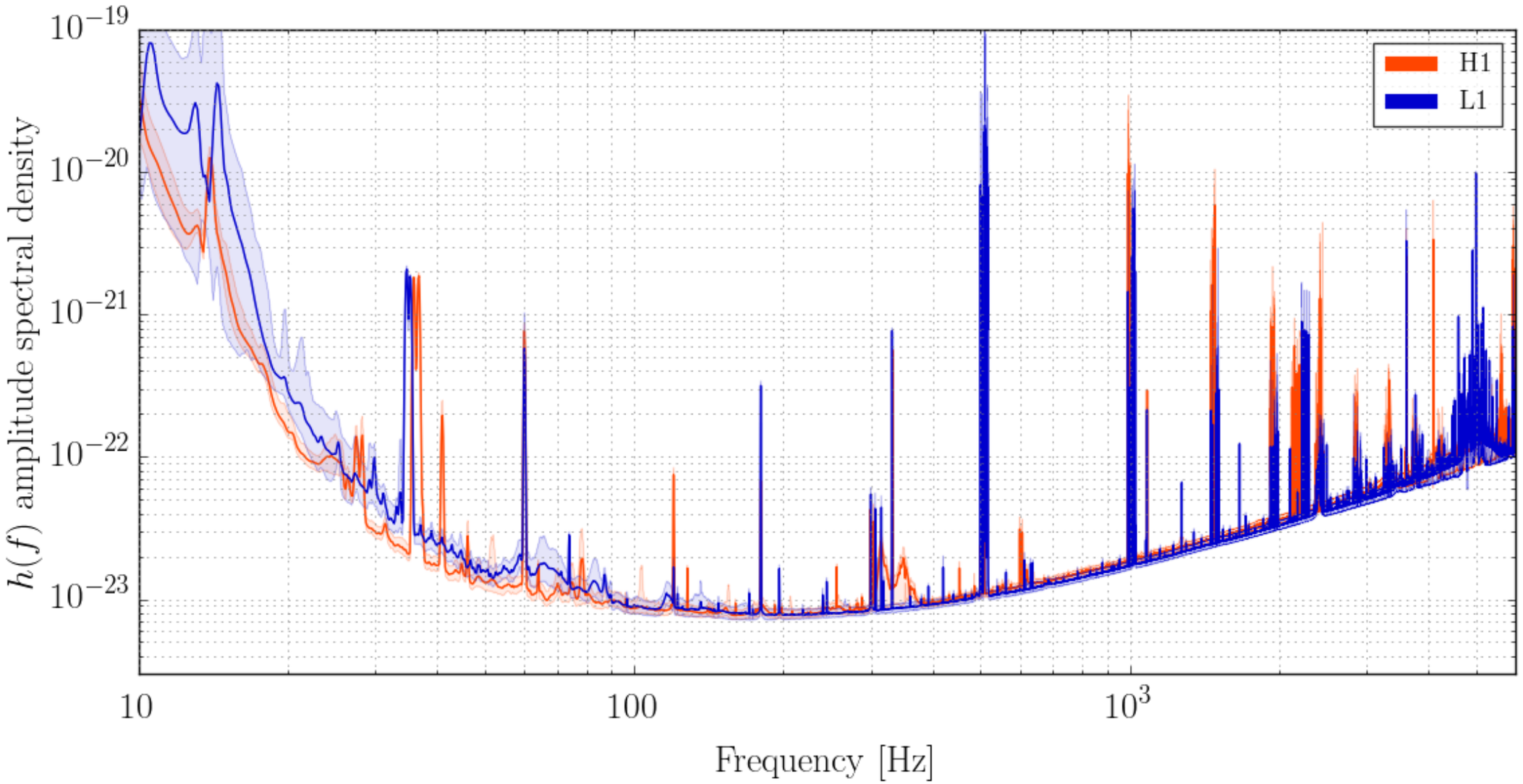


Signals in Strain Data: GW150914



see also Abbot et al., Phys Rev Lett **116**, 061102 (2016)

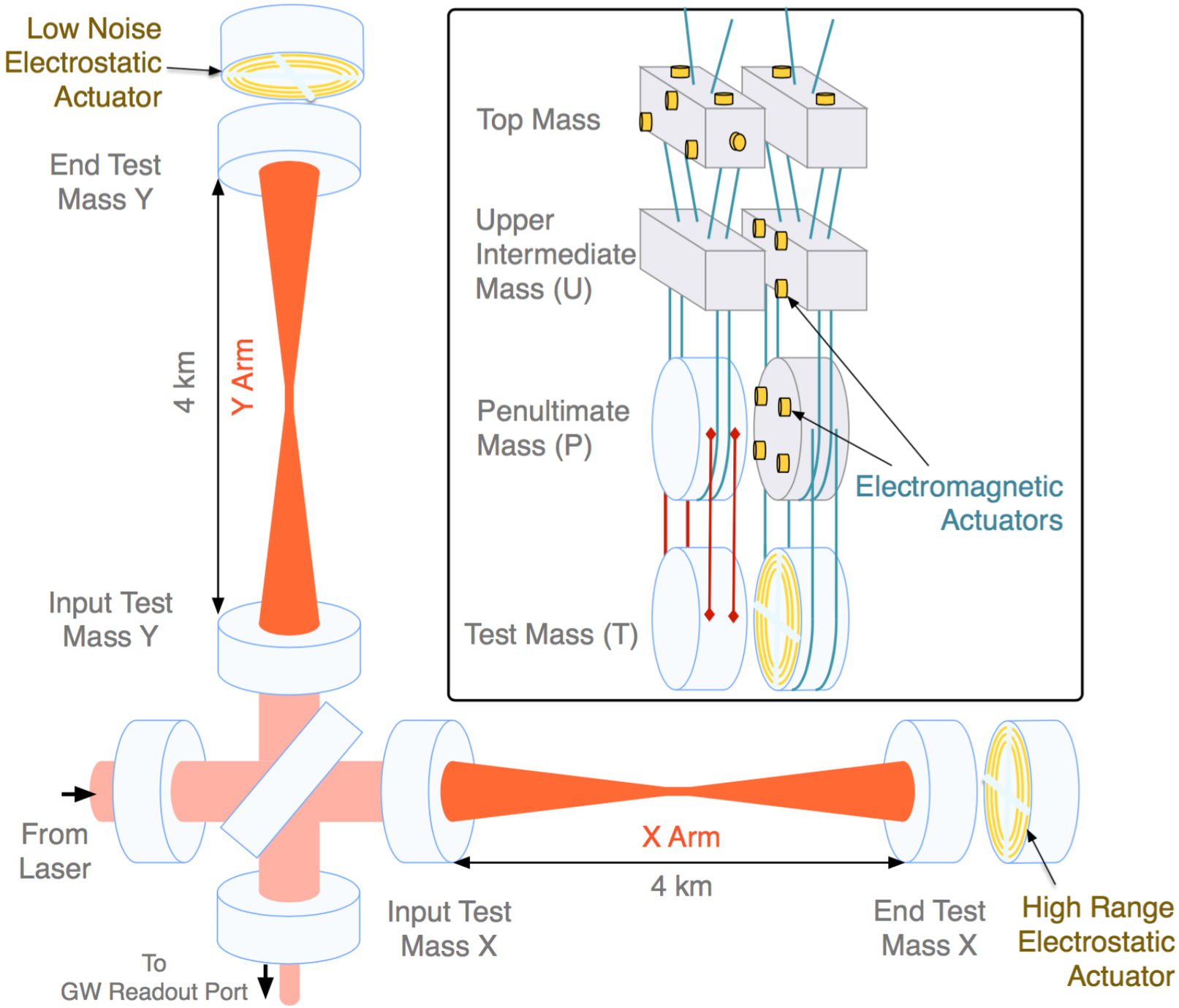
Calibrated Strain



Source: https://losc.ligo.org/events/GW150914/

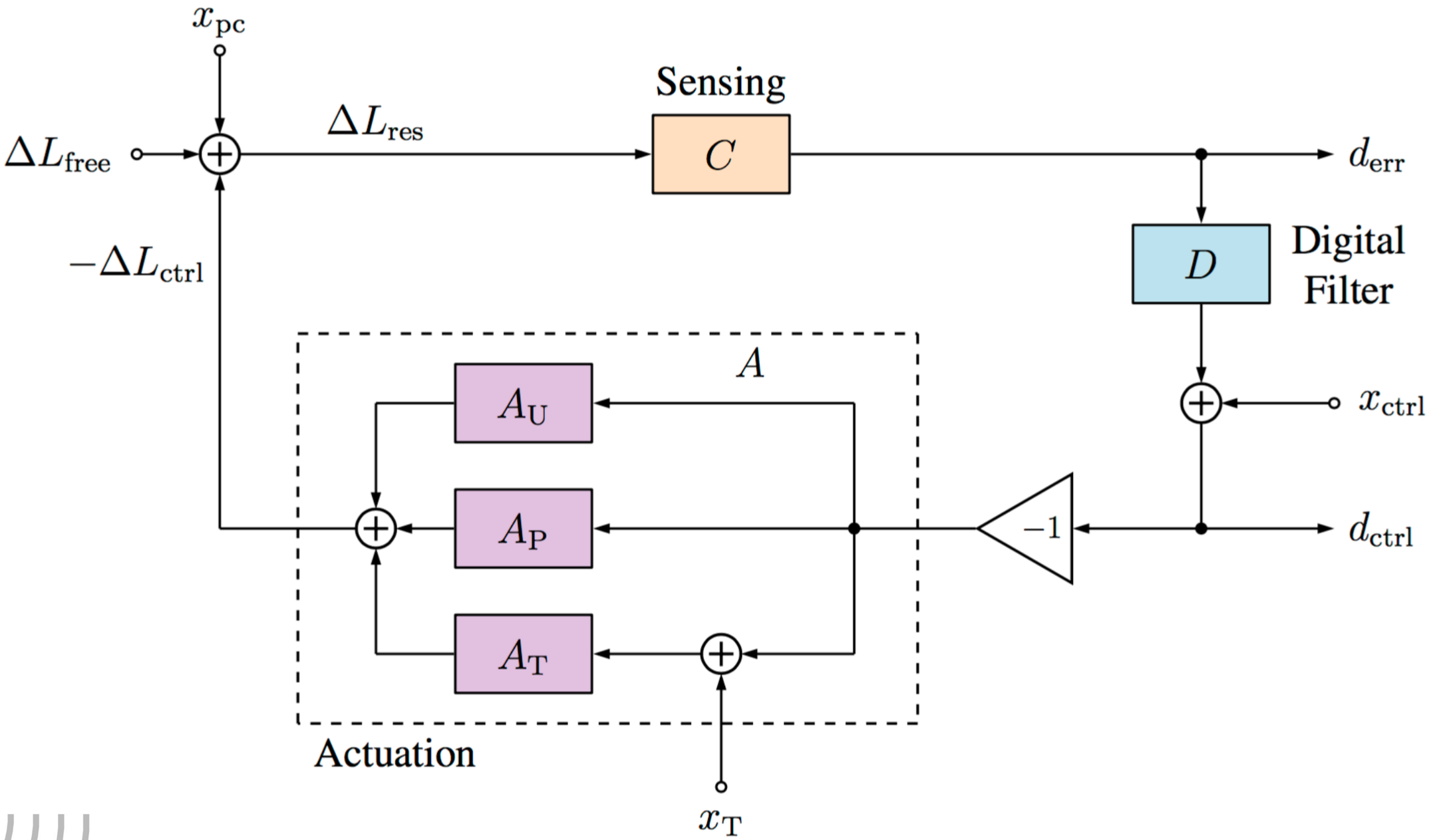
computed within ~5 s and broadcast to computing clusters received by analysis pipelines to rapidly search for signals

LIGO Calibration 101



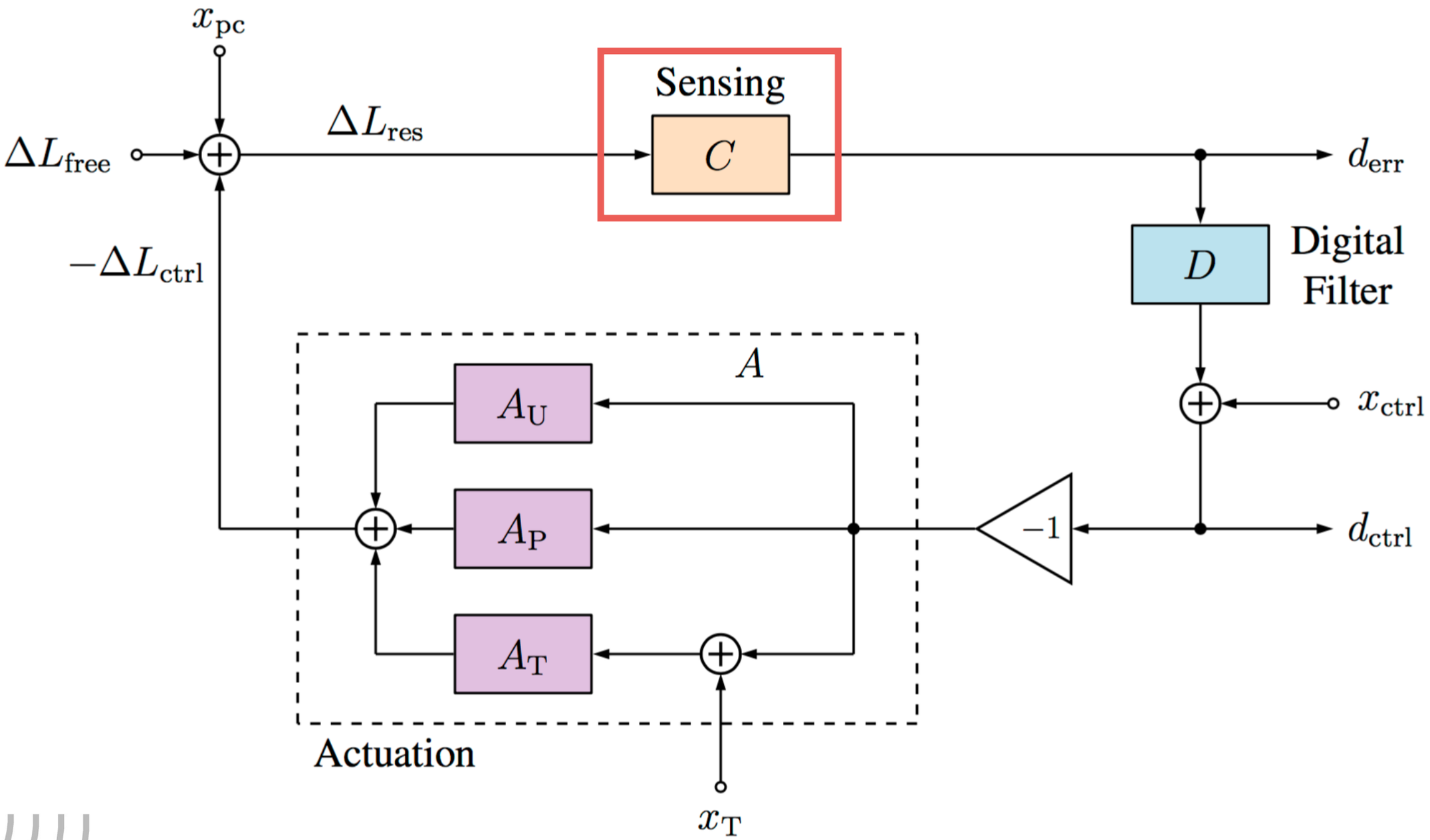
Abbot et al., Phys Rev D, **95**, 062003 (2017)

Calibration 101: Control Loop



Viets et al., arXiv 1710.09973 (accepted to CQG)

Calibration 101: Control Loop



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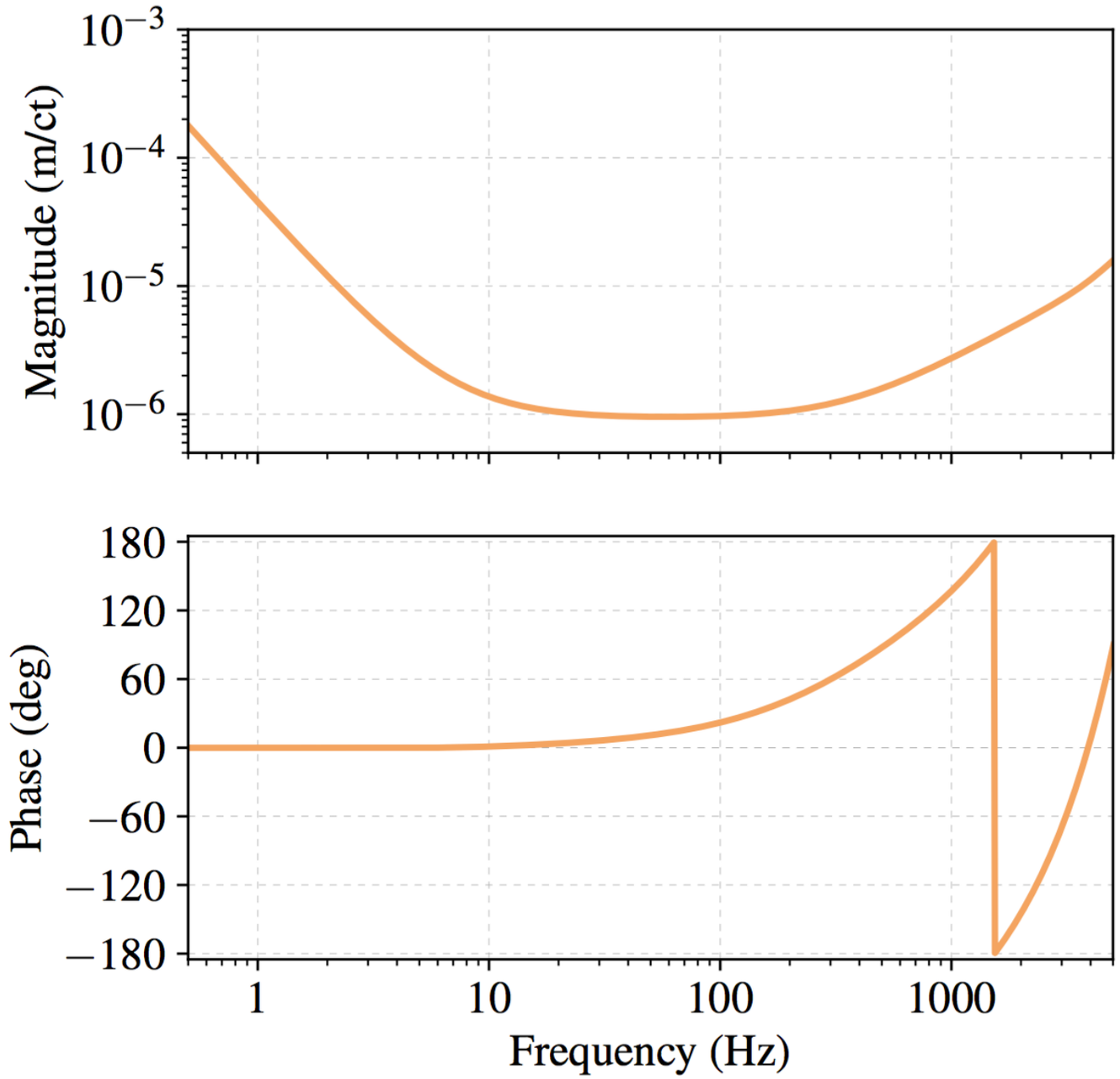
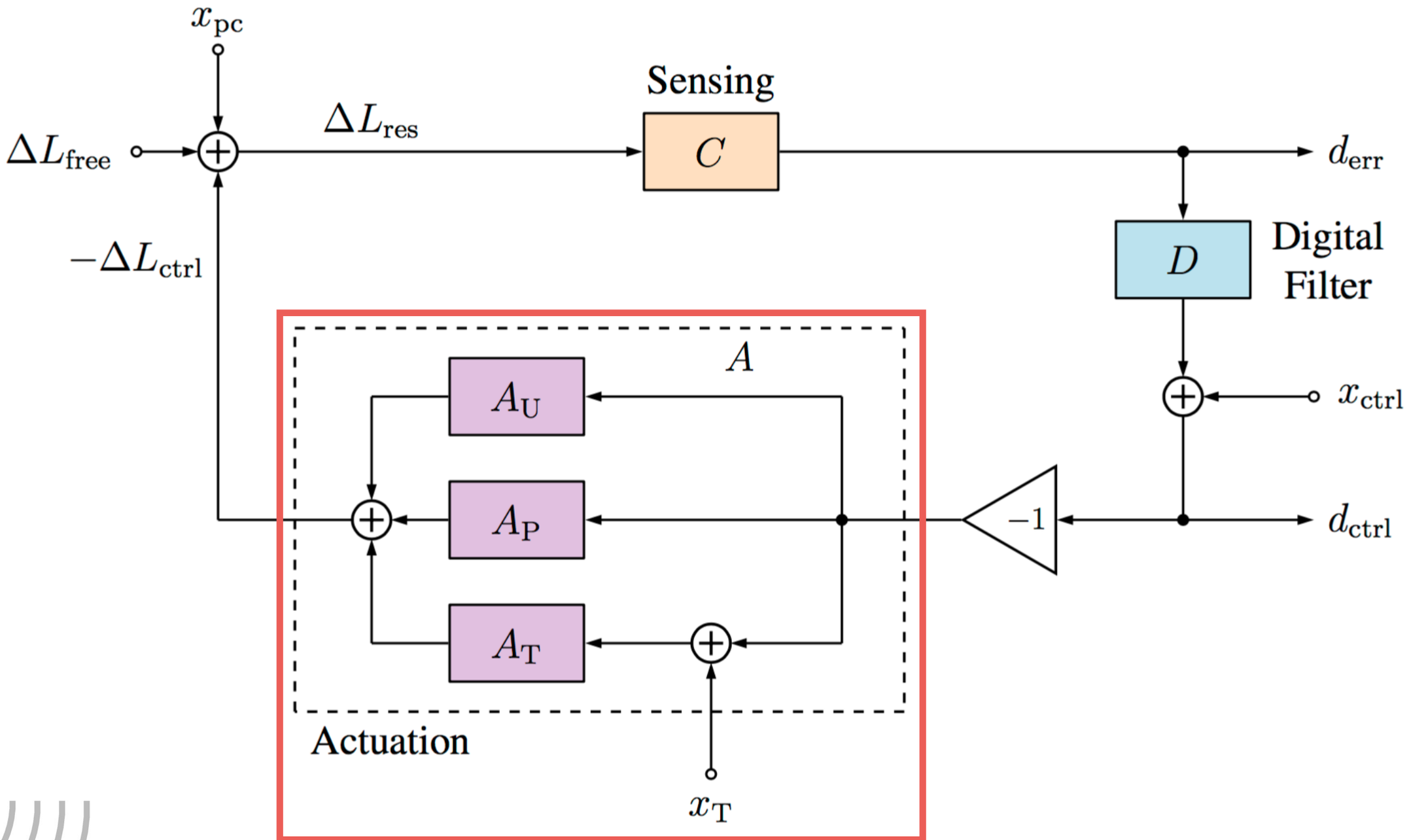


Viets et al., arXiv 1710.09973 (accepted to CQG)

Inverse Sensing

converts from photodiode
counts to residual length change

Calibration 101: Control Loop



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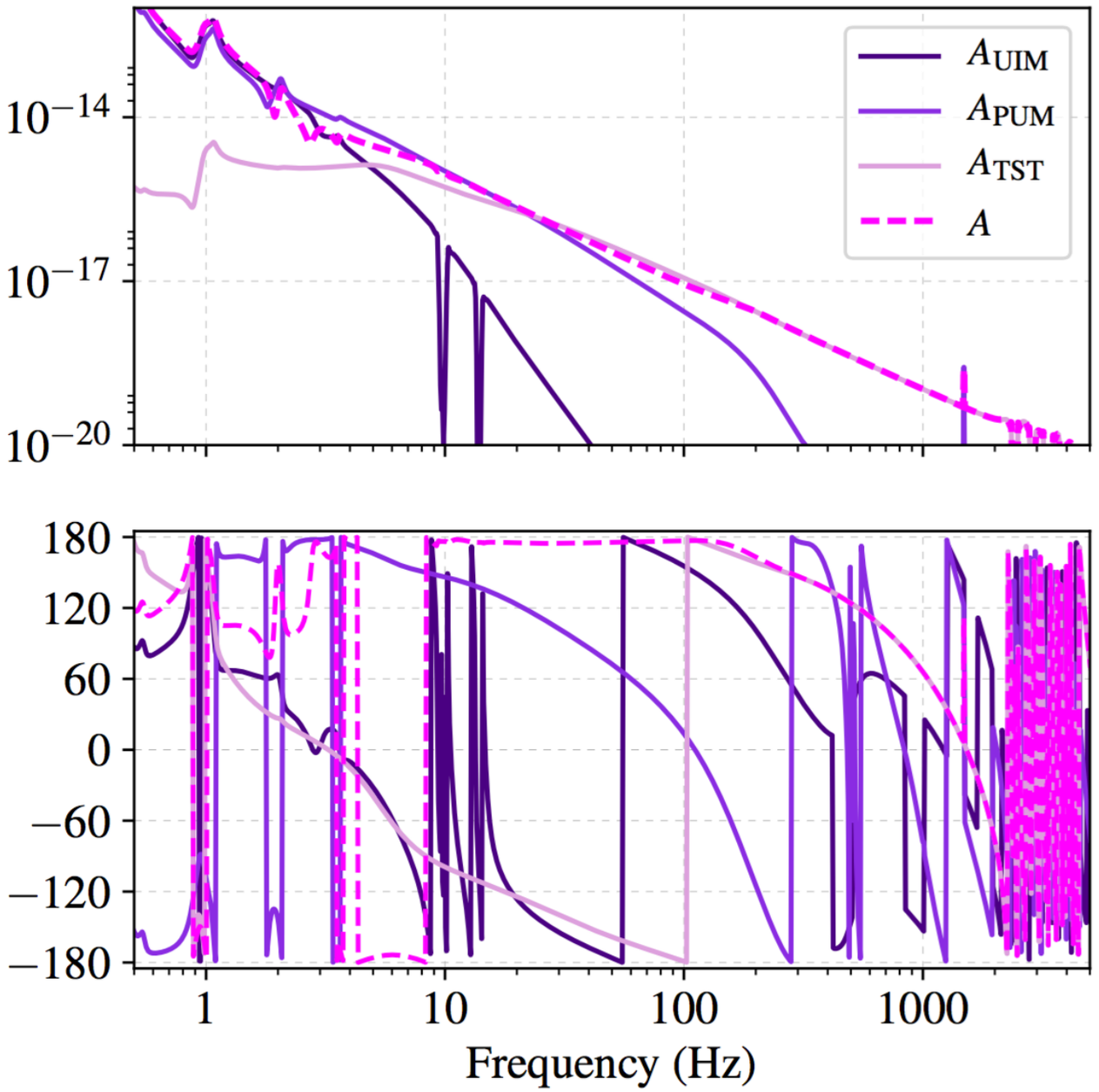
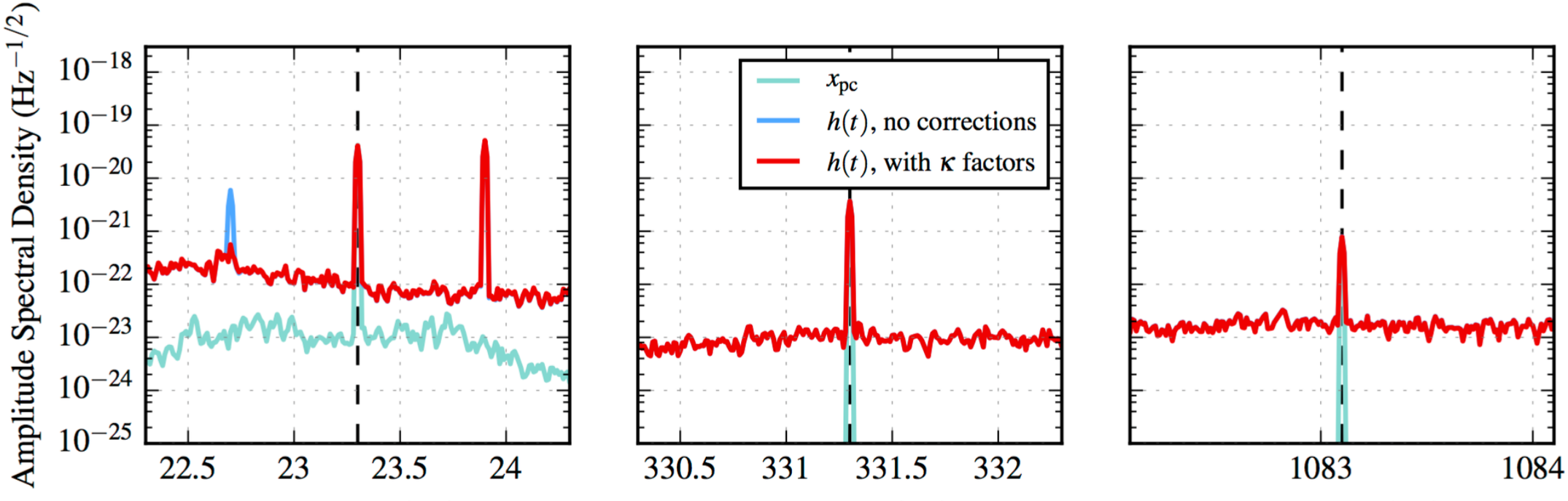


Viets et al., arXiv 1710.09973 (accepted to CQG)

Actuation

converts from control signal to controlled length change

Calibration Lines



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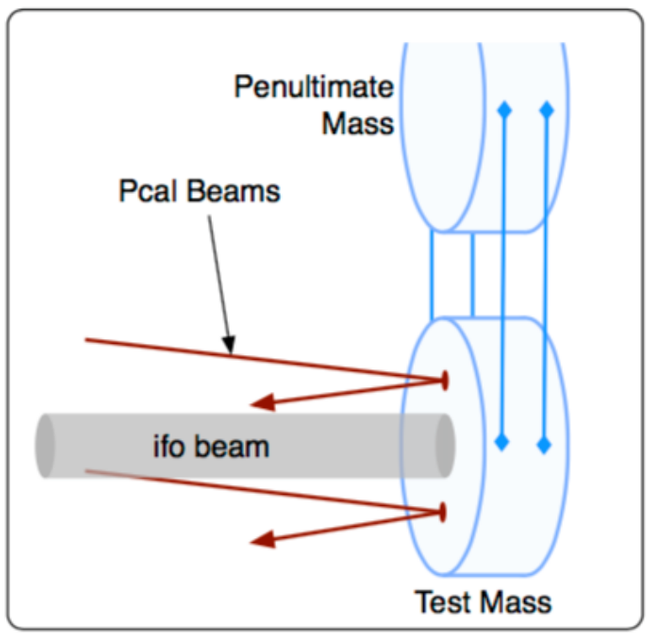


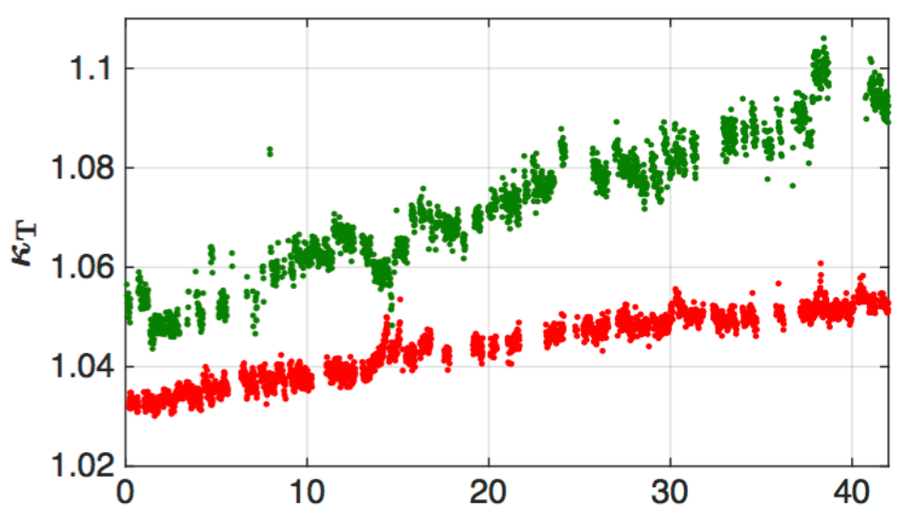
Karki et al., Review of Scientific Instruments **87**, 114503 (2016)

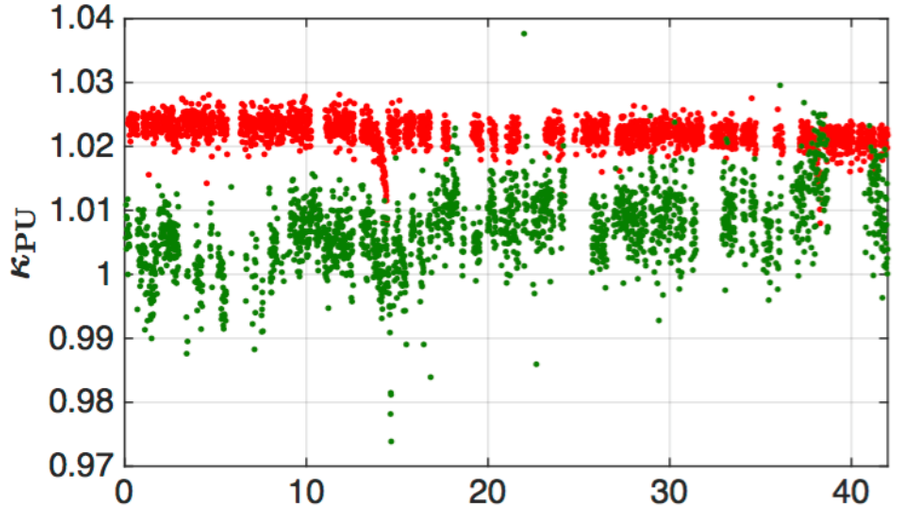
SNR ~ 100 sinusoidal excitations at certain frequencies

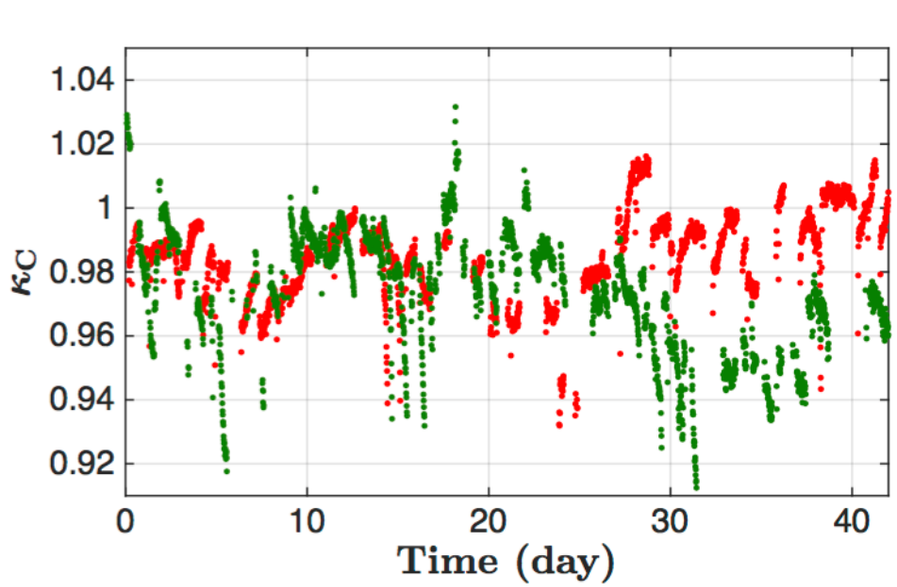
injected using suspension actuators and a photon calibrator

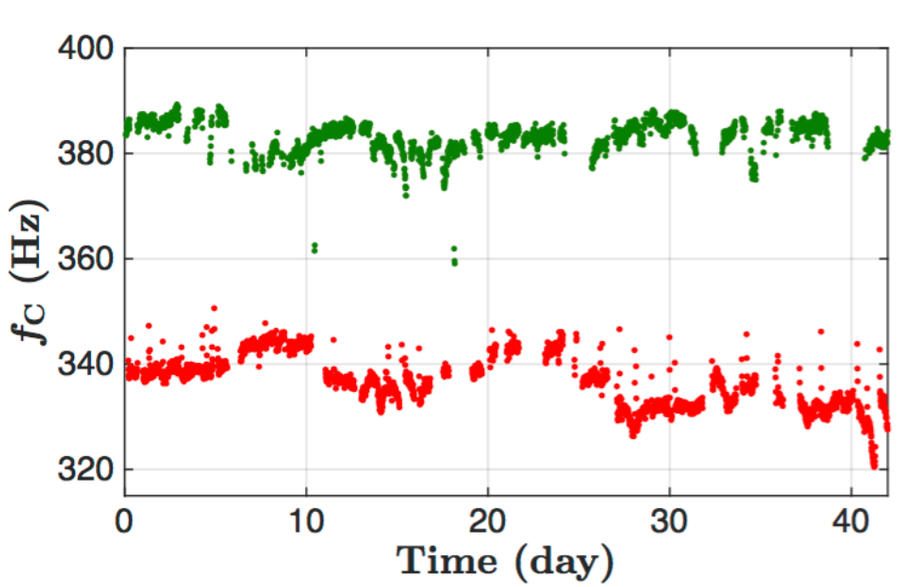
(in O2, data cleaning can remove these lines)

Calibration Lines







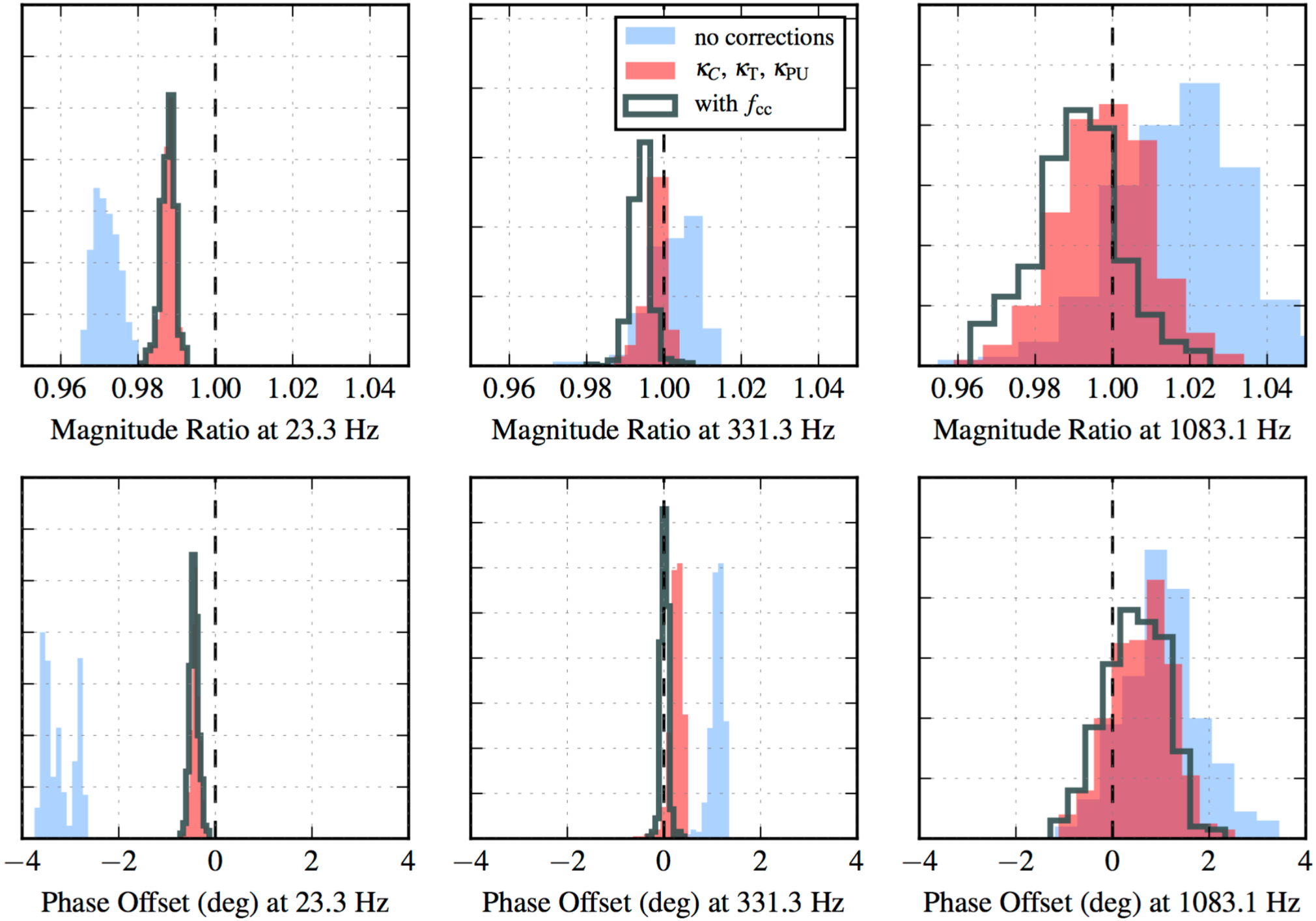


Tuyenbayev et al., CQG **34**, 015002 (2016)

can be used to track ~10% level fluctuations in scale and bandwidth

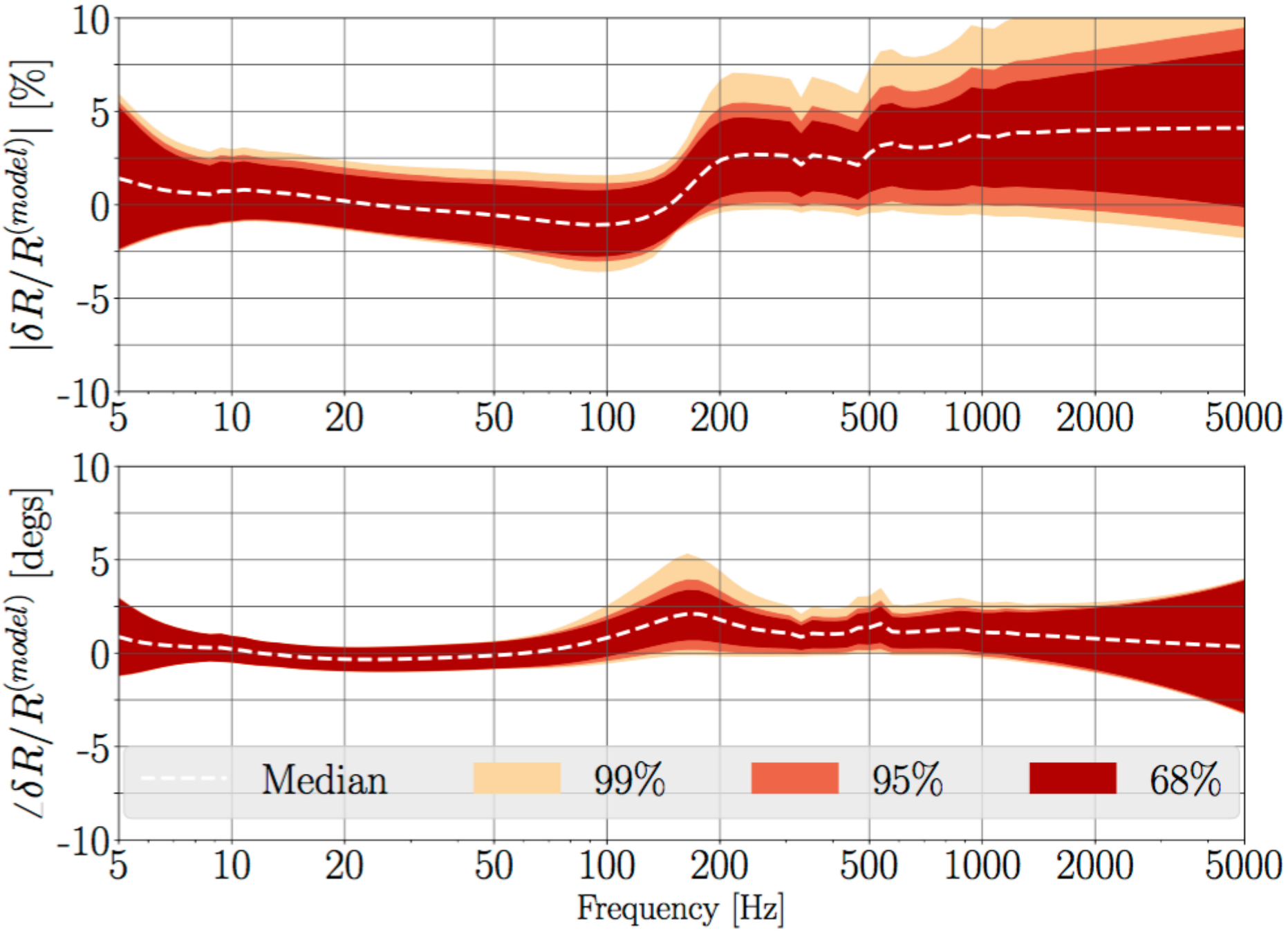
this ultimately reduces systematics

Systematics and Uncertainty



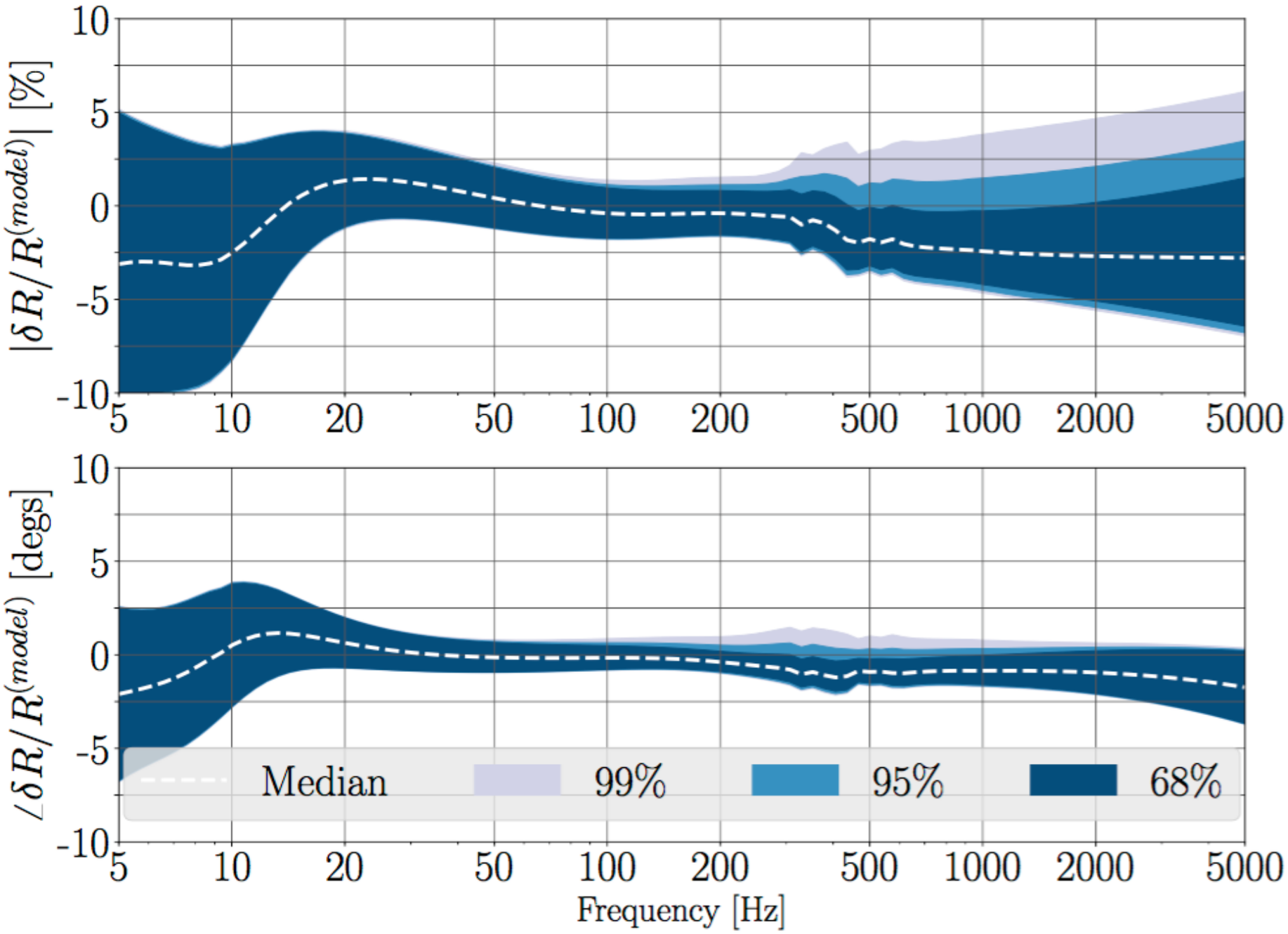
Viets et al., arXiv 1710.09973 (accepted to CQG)

Systematics and Uncertainty (H1)



Cahillane et al. arXiv 1708.03023

Systematics and Uncertainty (H1)



Cahillane et al. arXiv 1708.03023

Conclusion

- Advanced LIGO calibration is good, and getting better
- Strain is calibrated with more precision and smaller systematics in O2 compared to O1
- Slow variations in the interferometer are tracked and compensated for, reducing systematic bias in calibration
- In the future we can improve yet further by compensating for small changes in detector bandwidth

Conclusion

```
>>> from gwpy.timeseries import TimeSeries
>>> data = TimeSeries.fetch_open_data('L1', 1131350417, 1131357617)
```

We can demodulate the **TimeSeries** at 331.3 Hz with a stride of once per minute:

```
>>> amp, phase = data.demodulate(331.3, stride=60)
```

We can then plot these trends to visualize changes in the amplitude and phase of the calibration line:

```
>>> from gwpy.plotter import TimeSeriesPlot
>>> plot = TimeSeriesPlot(amp, phase, sep=True)
>>> plot.show()
```

Support for calibration line tests is
now a feature in GWPy
(see Duncan Macleod's tutorial)

Questions?