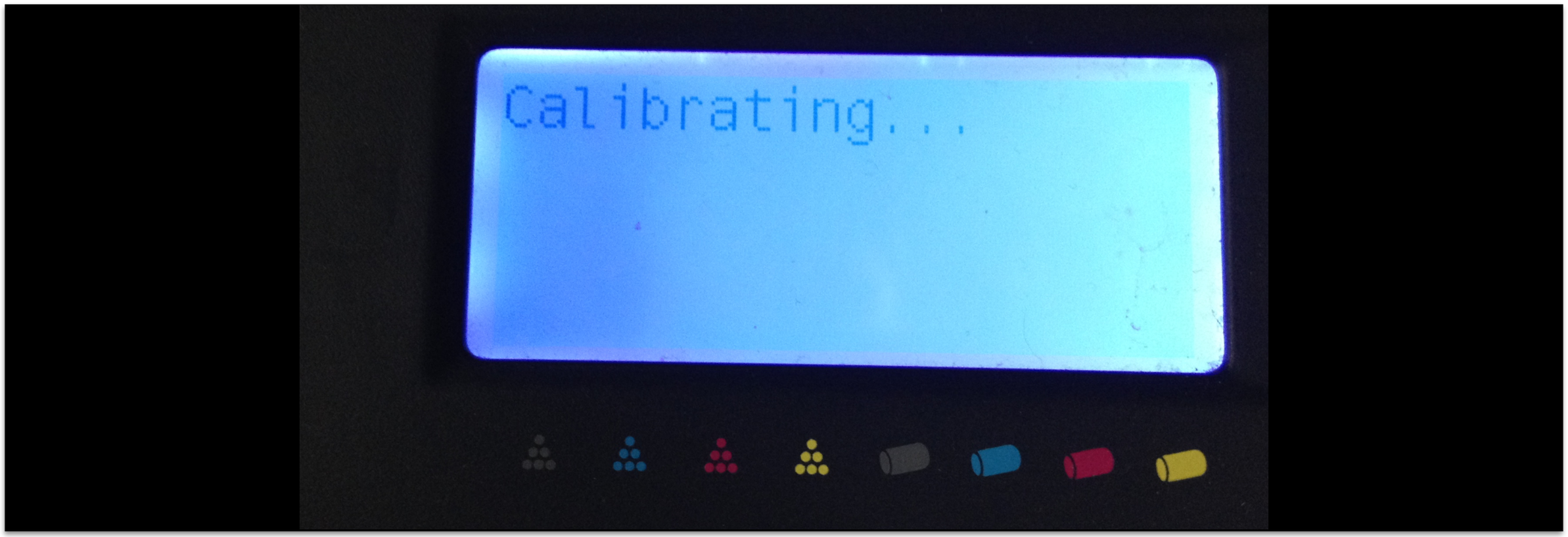
Calibration Improvements

in Advanced LIGO's Second Observing Run



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ON BEHALF OF THE ADVANCED LIGO CALIBRATION GROUP

Amaldi 12, July 10, 2017
LIGO Document G1701302

Outline of This Talk

- (Extremely) cartoonish picture of Advanced LIGO calibration
- Overview of *h*(*t*) calibration pipeline
- Improvements in O2: online tracking and compensating for slow variations
- Impact of these changes on astronomy

Who are we?

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

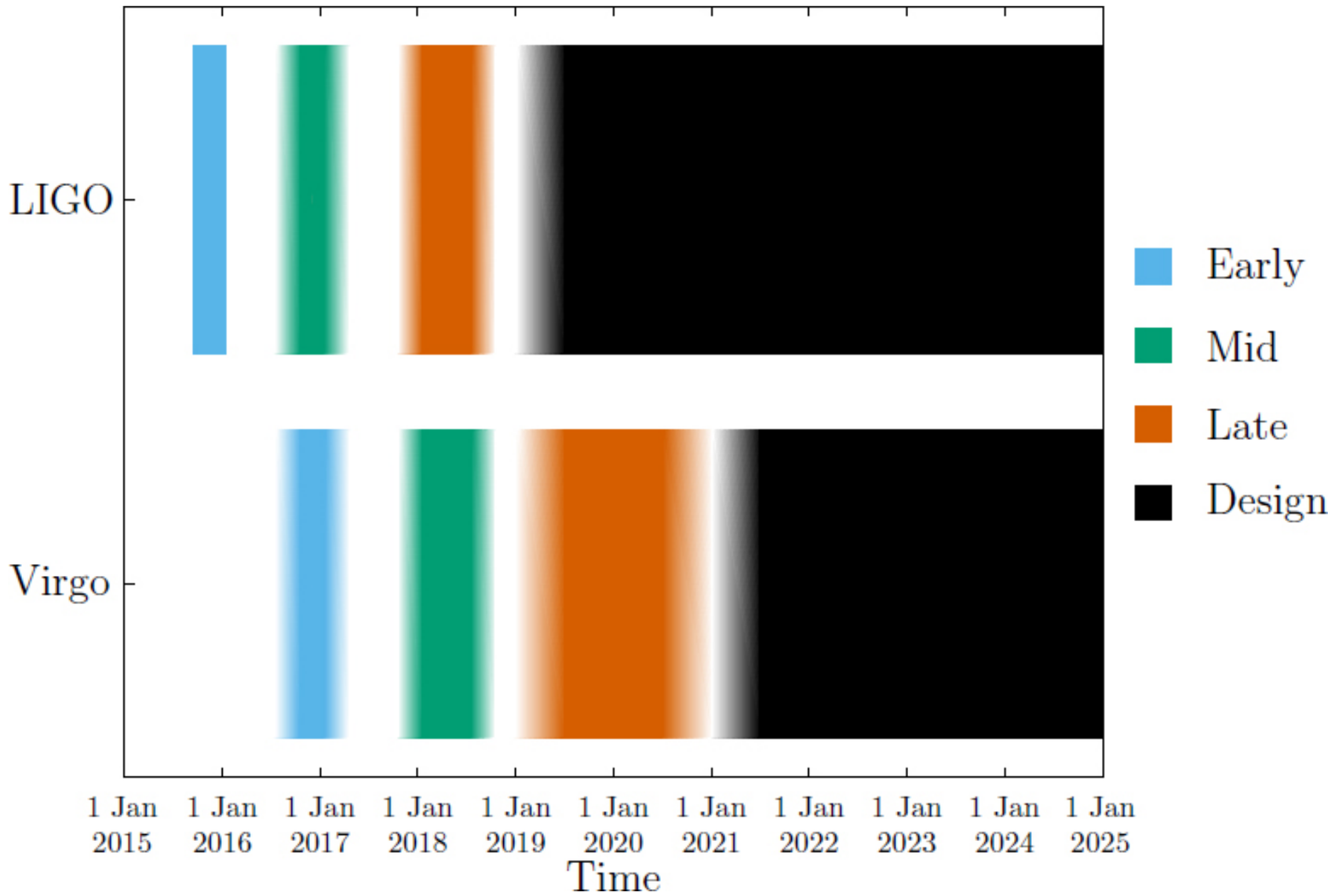
L1 H1

LIGO

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

THIS TALK FOCUSES ON LIGO

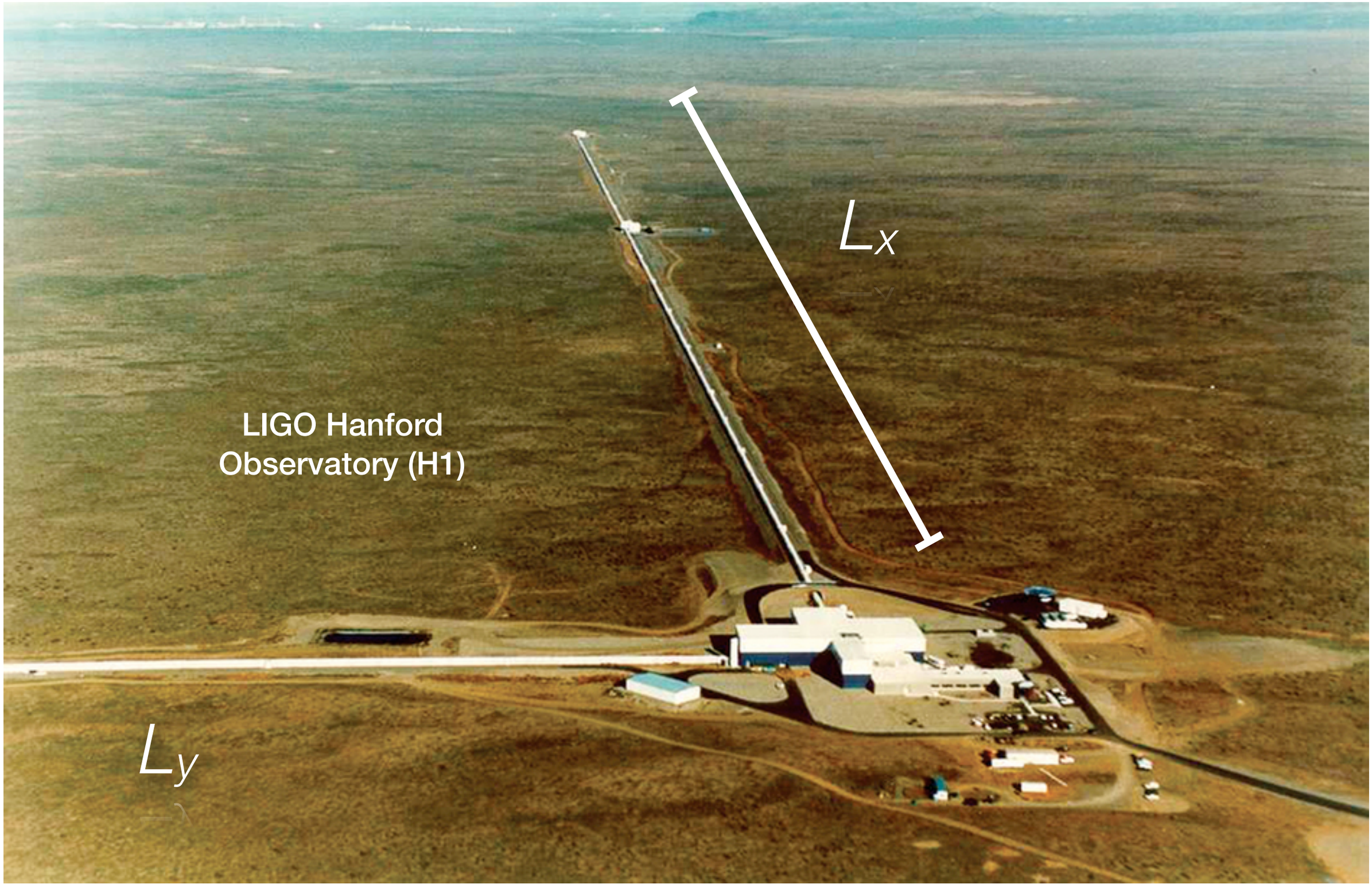
Observing Run Schedule



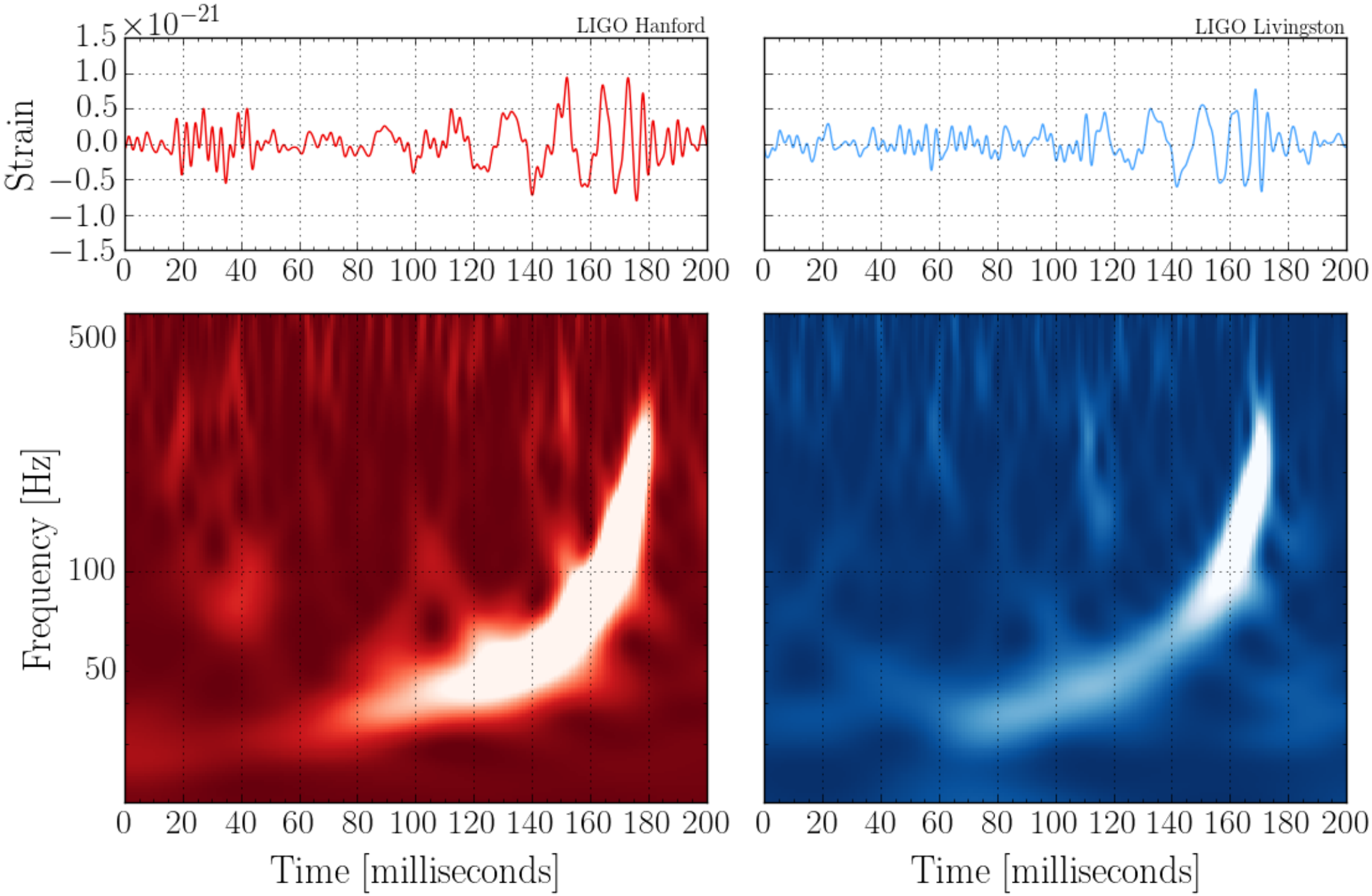
Abbot et al., Living Rev Relativ, 19: 1 (2016)

slightly out of date: O2 lasts from late 2016 through August, Virgo recently began taking data this summer

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

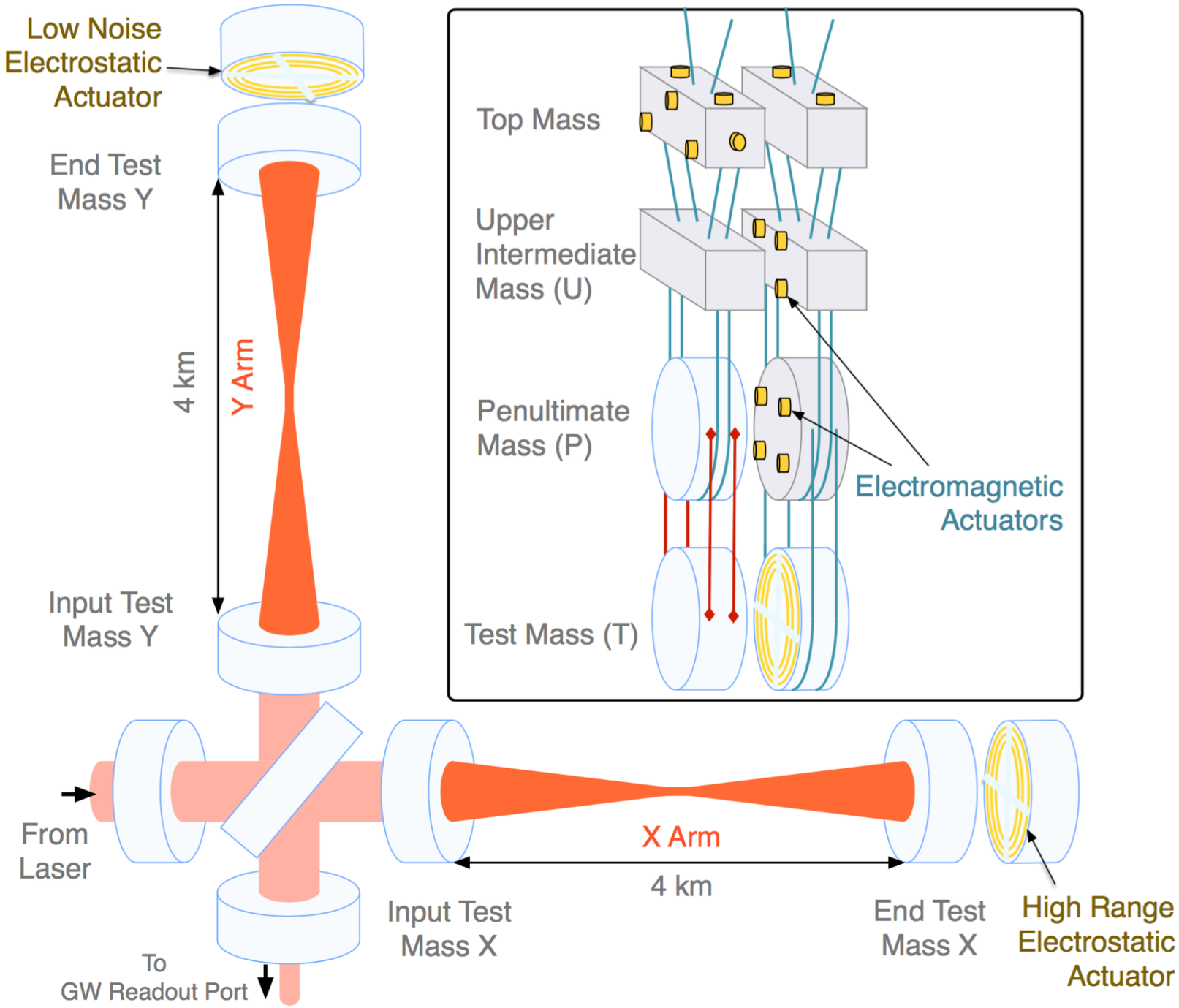


Signals in Strain Data: GW150914



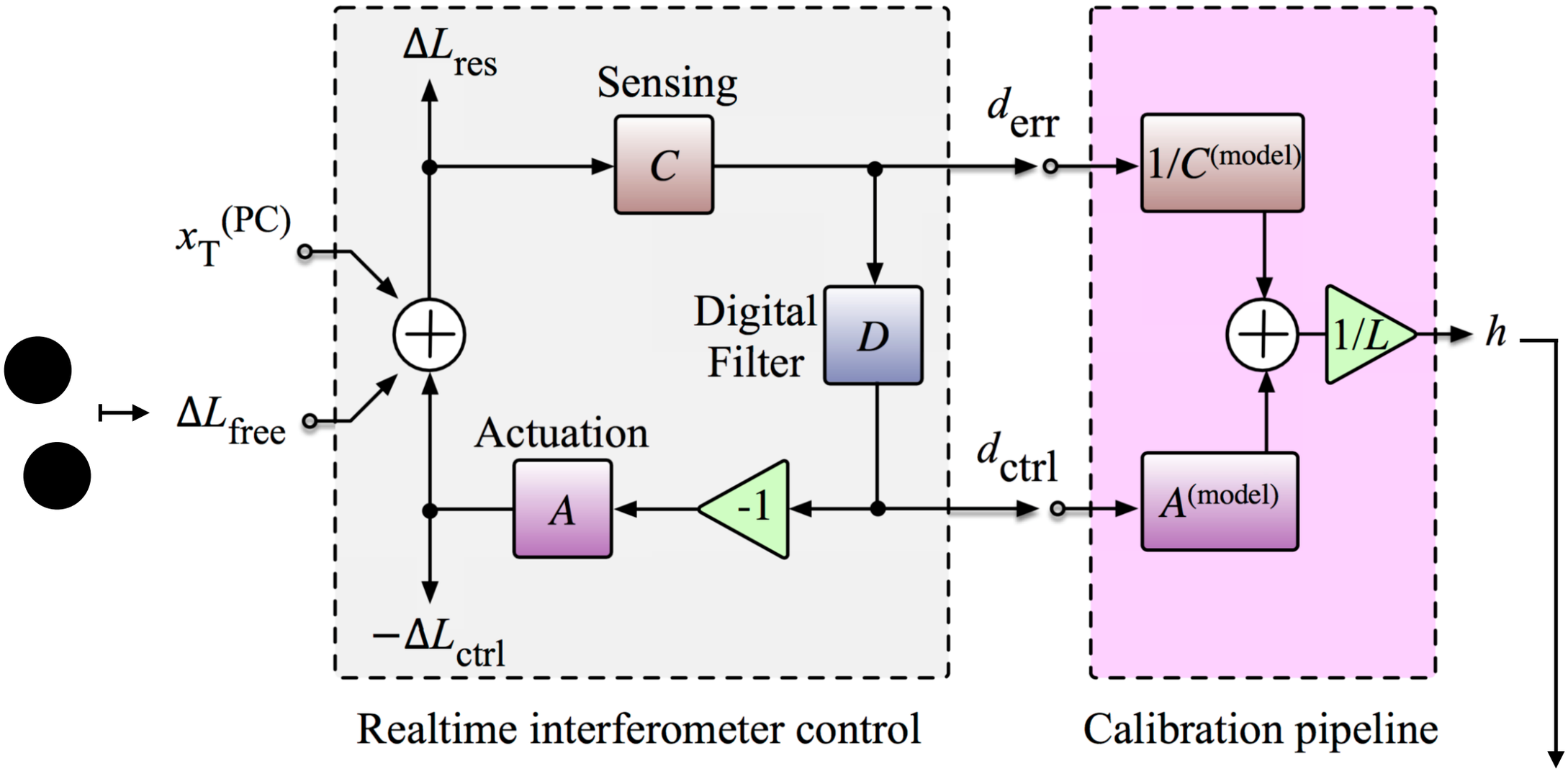
see also Abbot et al., Phys Rev Lett **116**, 061102 (2016)

Calibration 101

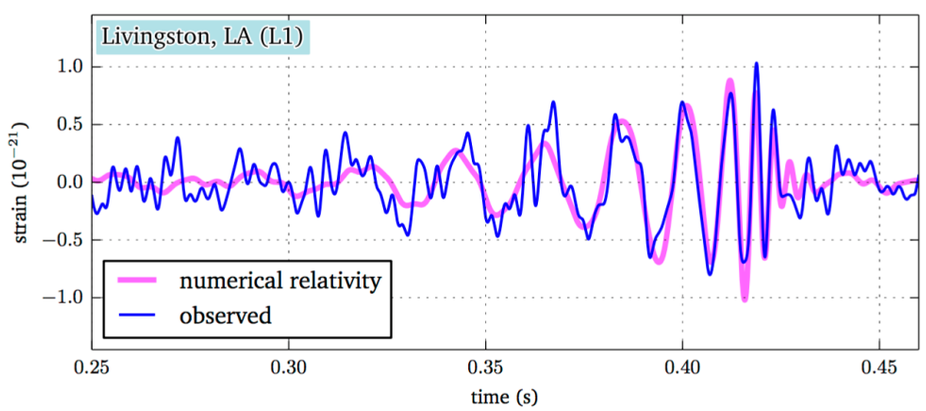


Abbot et al., Phys Rev D, **95**, 062003 (2017)

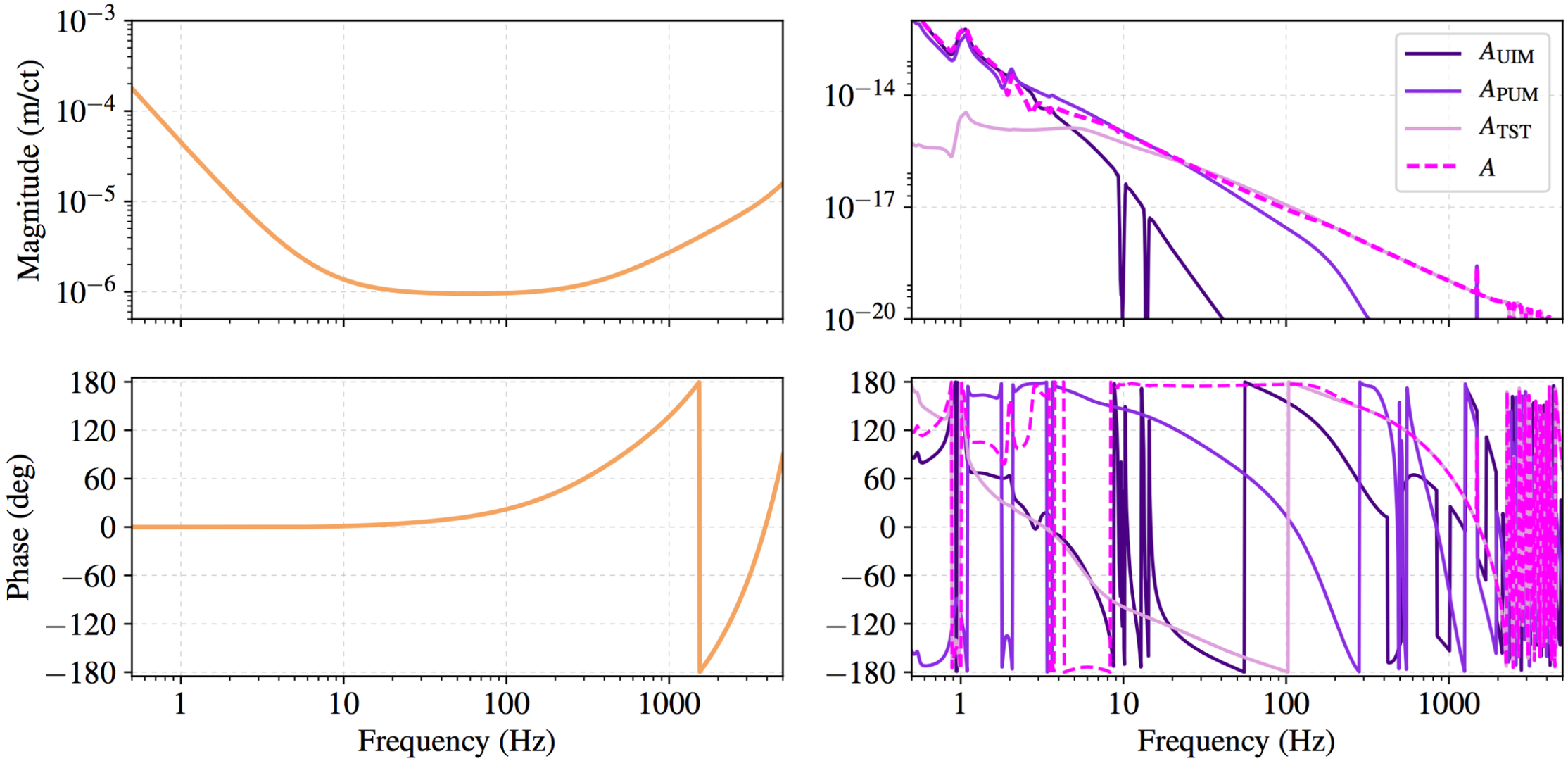
Calibration 101



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



Sensing and Actuation

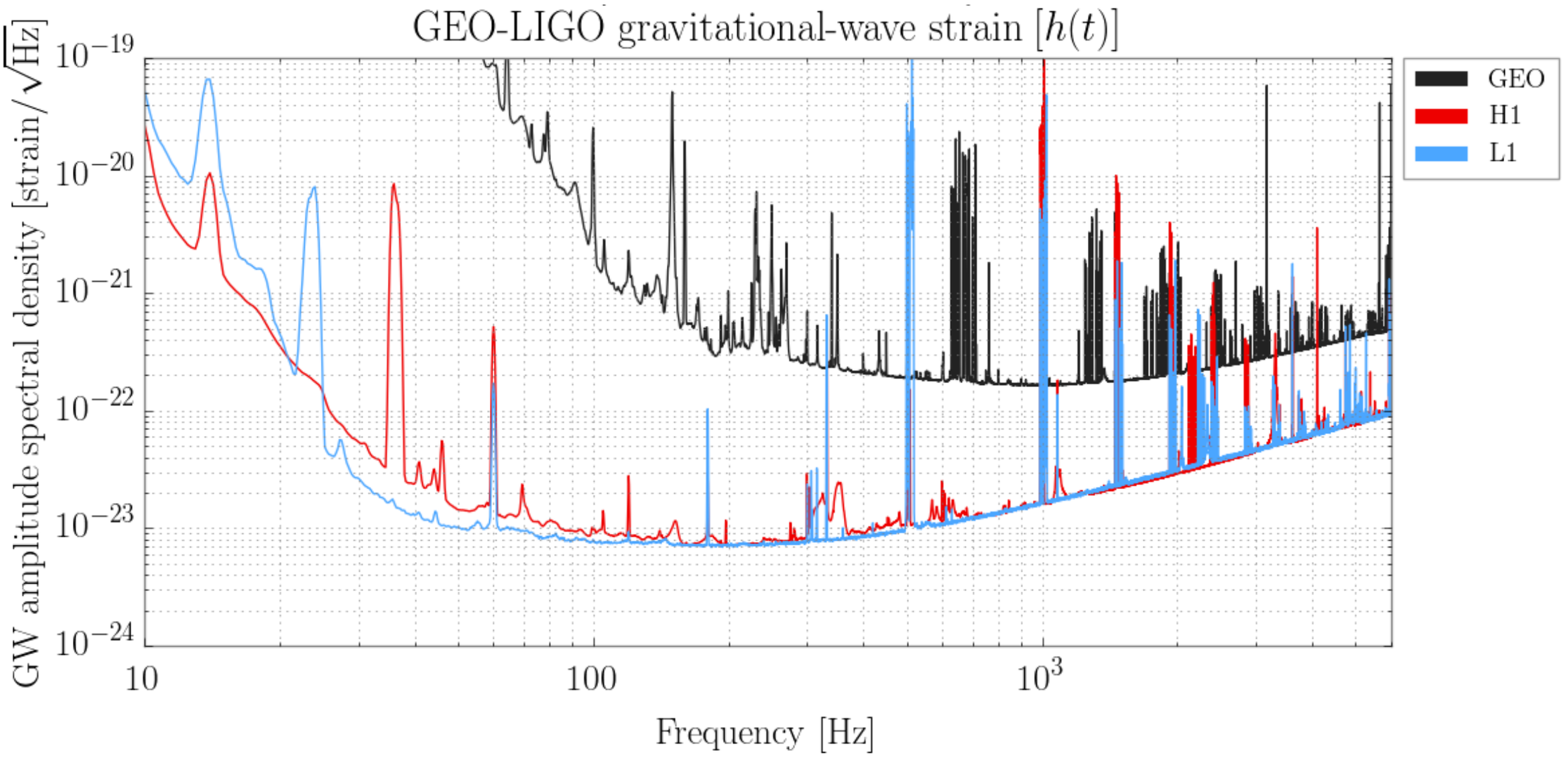


Viets et al., in prep

Inverse Sensing
converts from photodiode counts to residual length change

Actuation
converts from control signal to controlled length change

Calibrated Strain



computed within ~5 s and broadcast to computing clusters received by analysis pipelines for rapid transient searches

Online vs. Offline

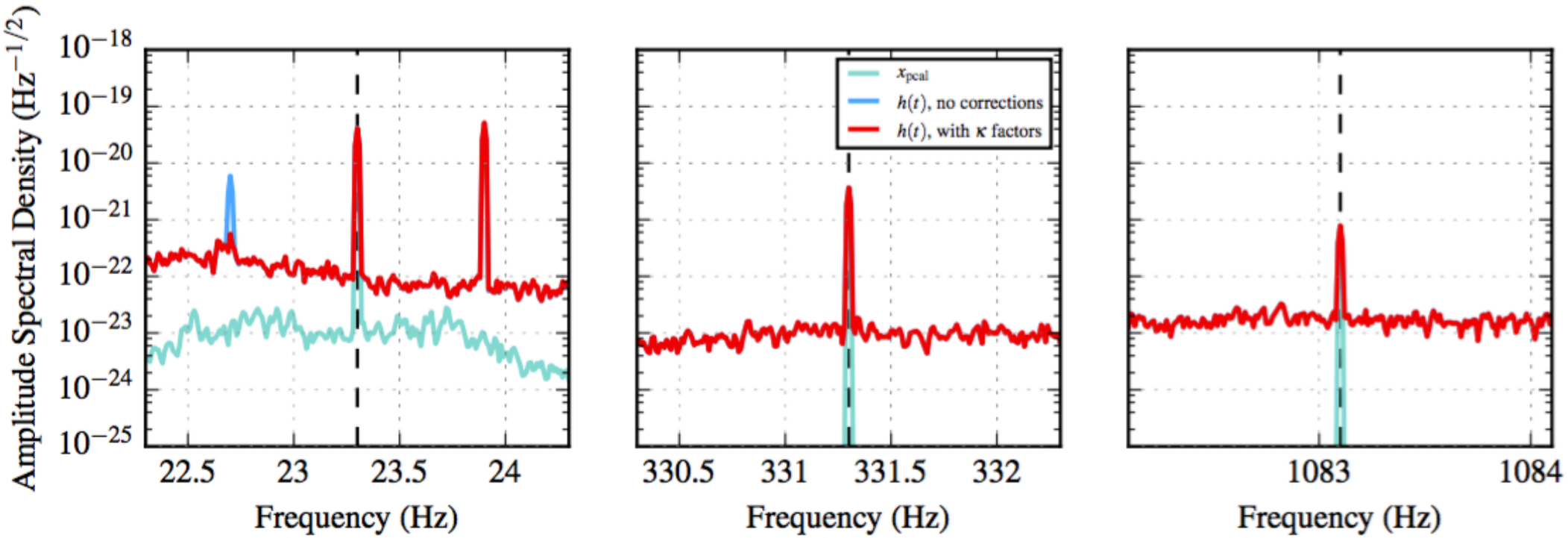
C00 (online)

- Computed within ~5 s
- Computed by filtering output of front-end controls
- May contain gaps and data dropouts

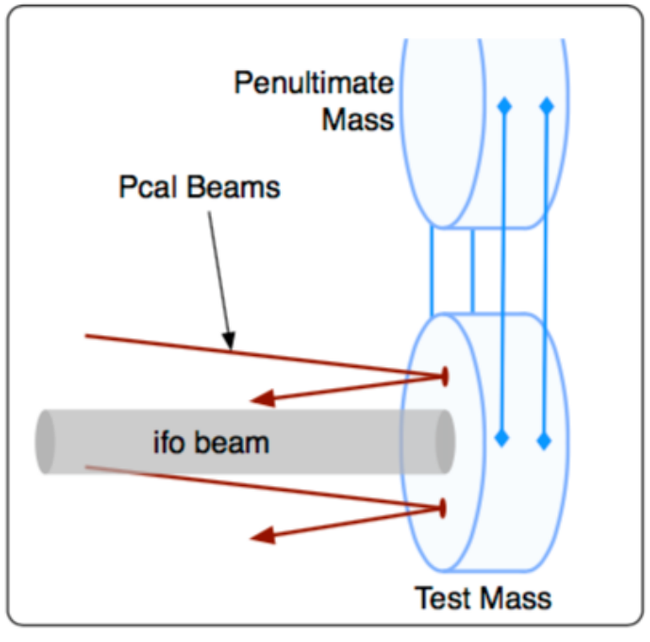
C01 (offline)

- Available within ~a few weeks/months
- Computed directly from error and control signals
- Fills in gaps and data dropouts

Calibration Lines



Viets et al., in prep

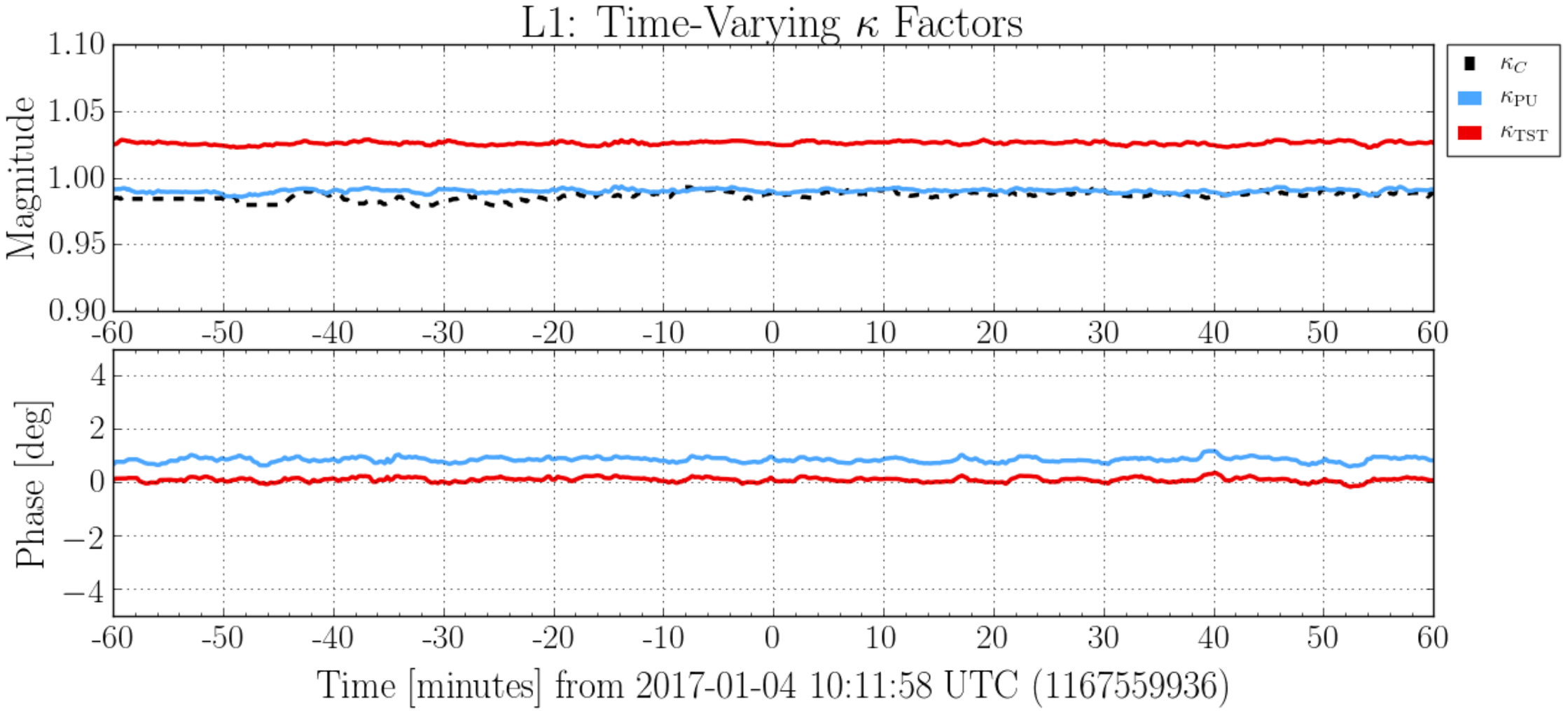


Karki et al., Review of Scientific Instruments **87**, 114503 (2016)

SNR ~ 100 sinusoidal excitations at certain frequencies

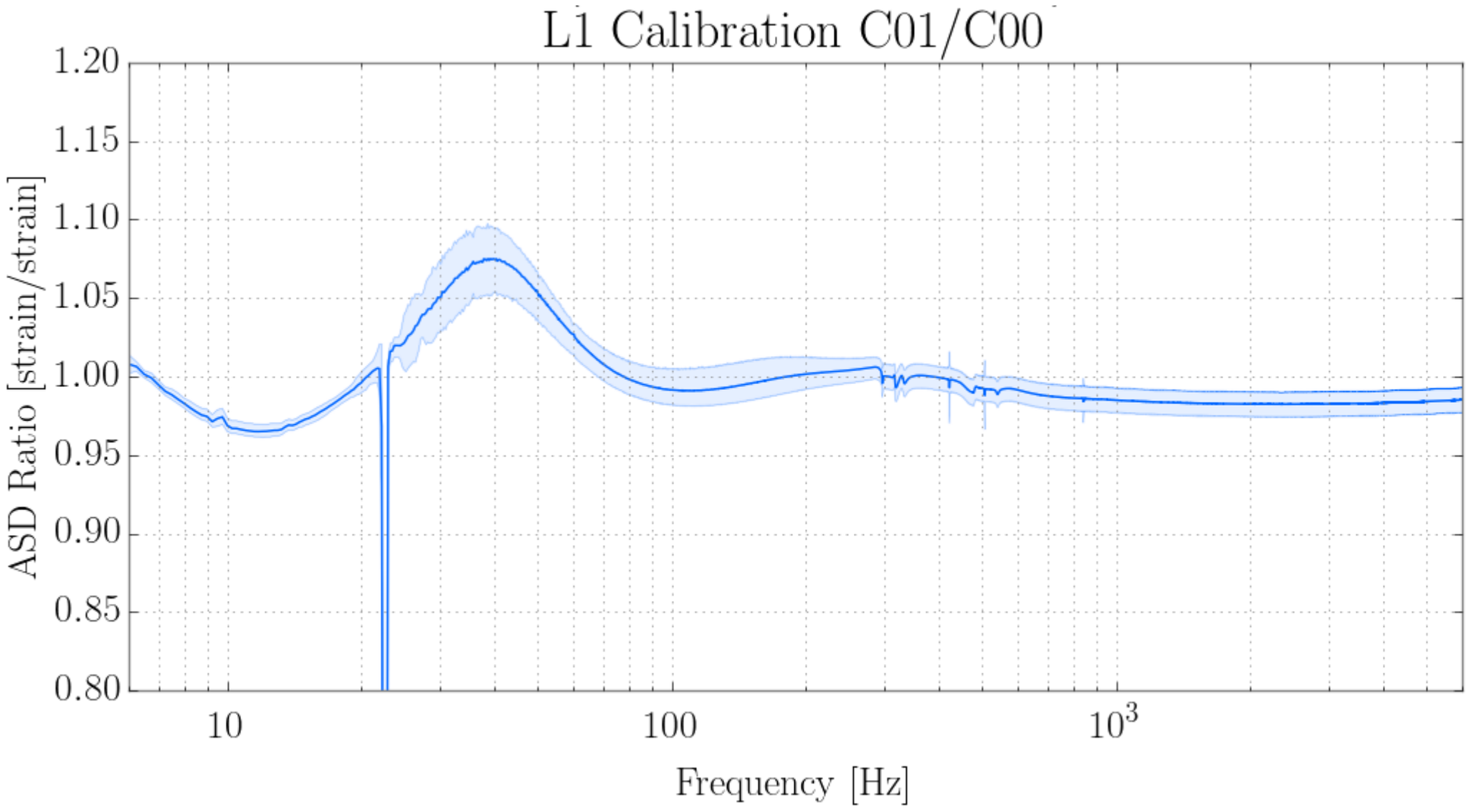
injected using suspension actuators and a photon calibrator

Scalar Time Variations



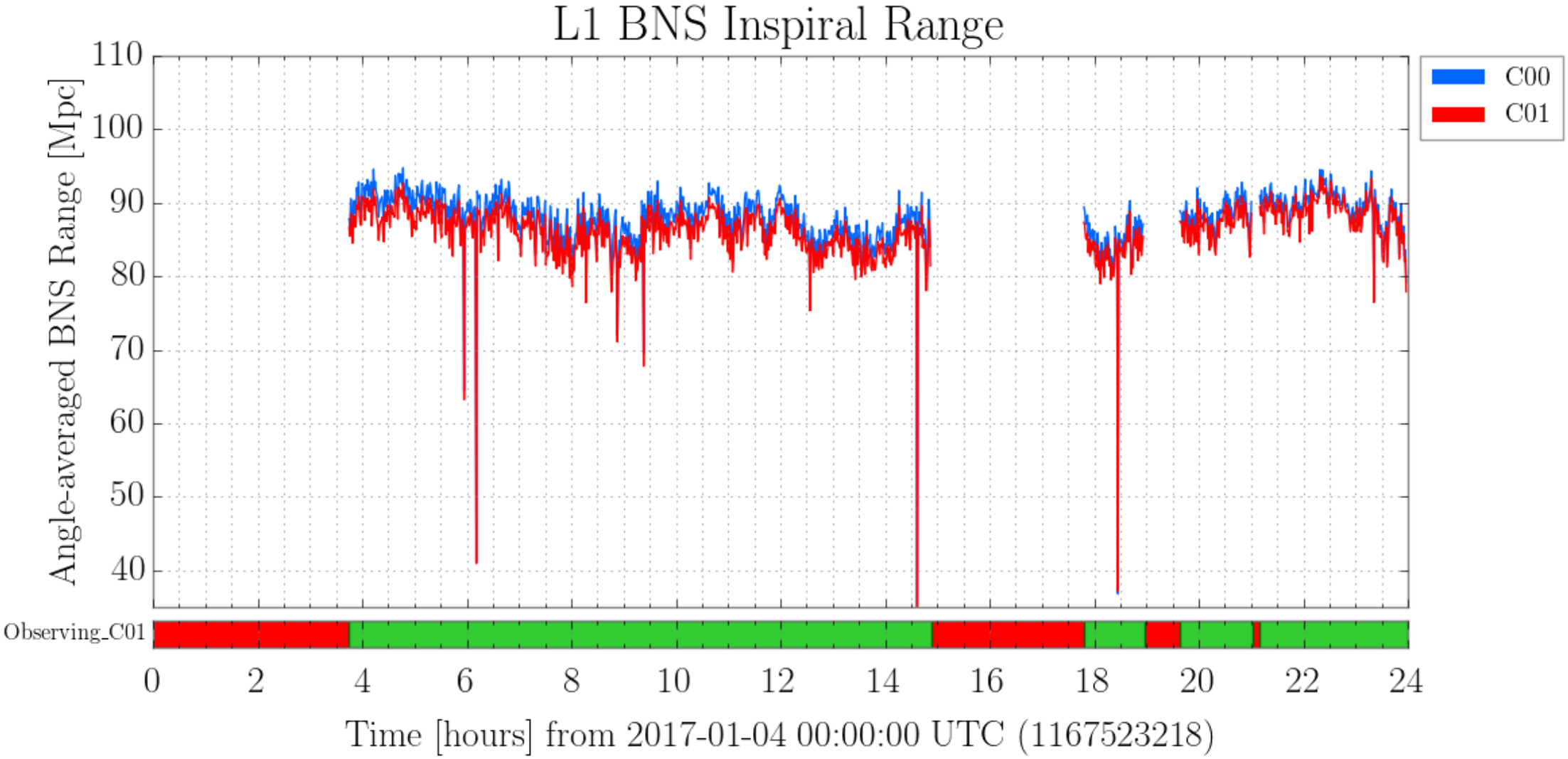
most deviations from sensing and actuation models can be approximated as slowly changing gains

Scalar Time Variations



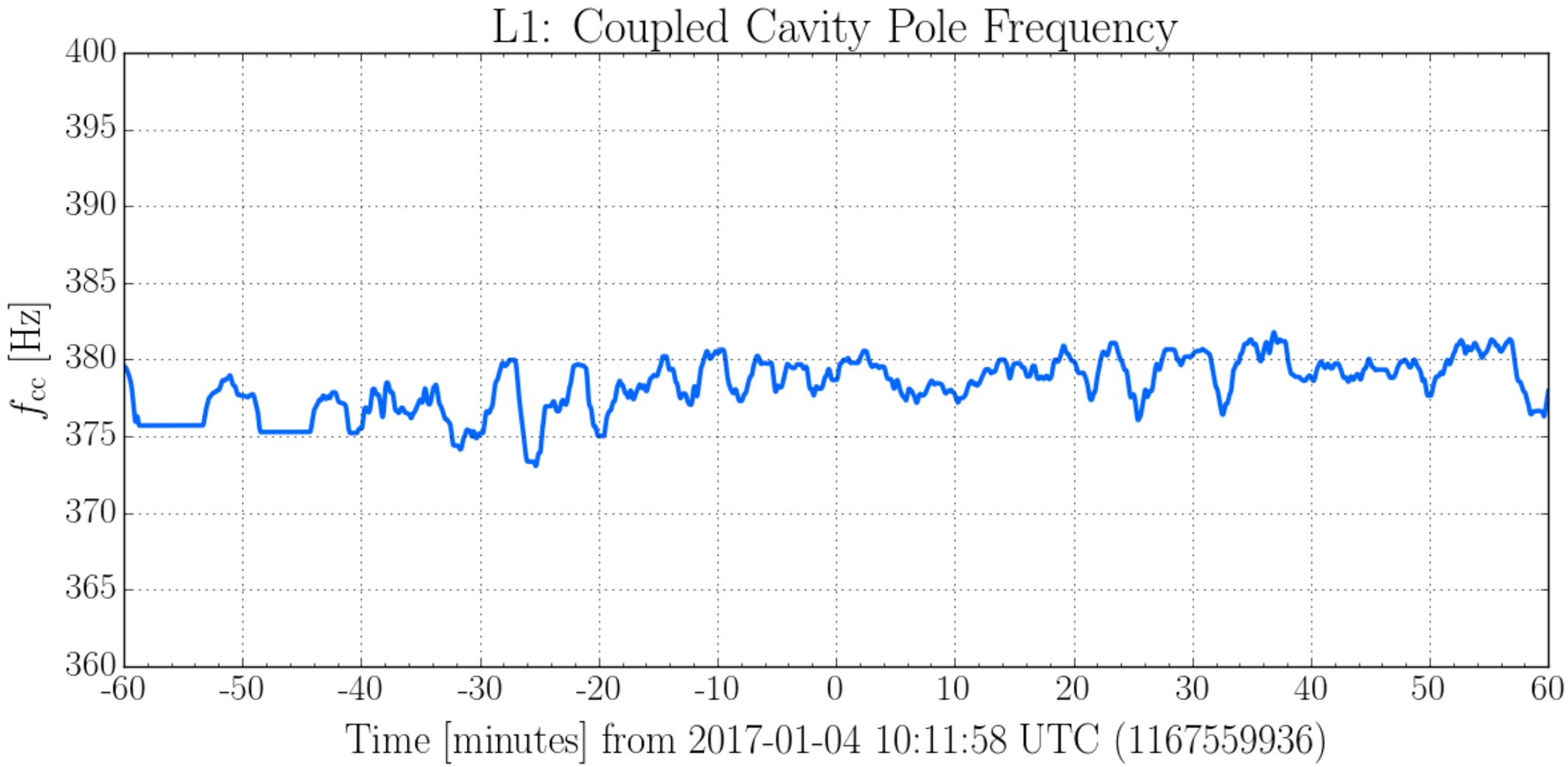
makes a ~1-10% difference across all frequencies
particularly low- and mid-range

Scalar Time Variations



translates into a ~few percent difference in BNS range
(sometimes an improvement, sometimes not)

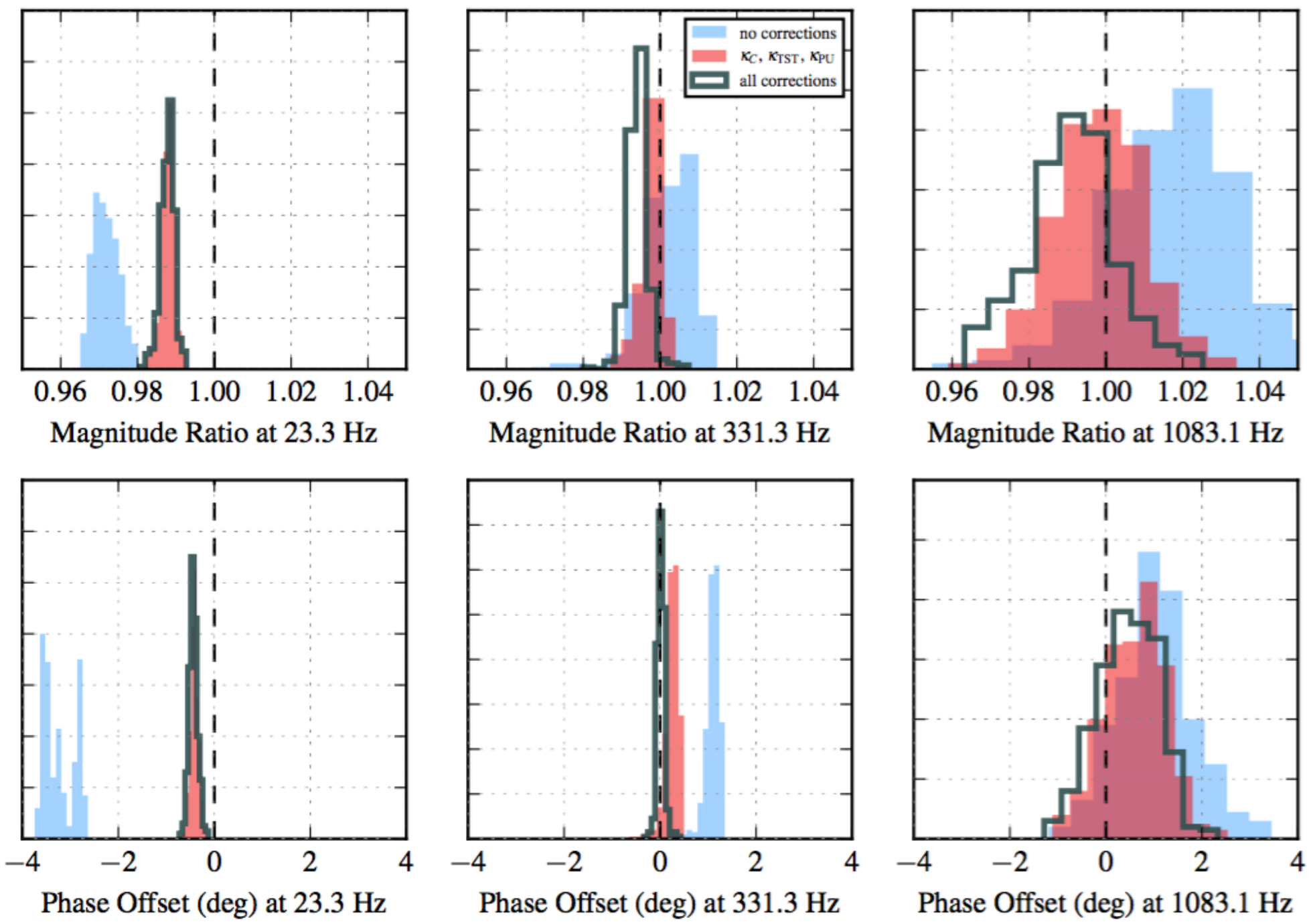
Scalar Time Variations



however, the coupled cavity pole is a time-changing corner frequency in a low-pass filter (the sensing function)

much harder to compensate for, but work is in progress

Systematic and Statistical Error



Viets et al., in prep (see also Cahillane et al., in prep)

Conclusion

- Low-latency data are calibrated with higher precision and smaller systematics in O2 (compared to O1 — see Craig's talk!)
- Slow variations in the interferometer are tracked and compensated for, both online and offline
- In the future we can improve yet further by compensating for time- and frequency-dependent changes

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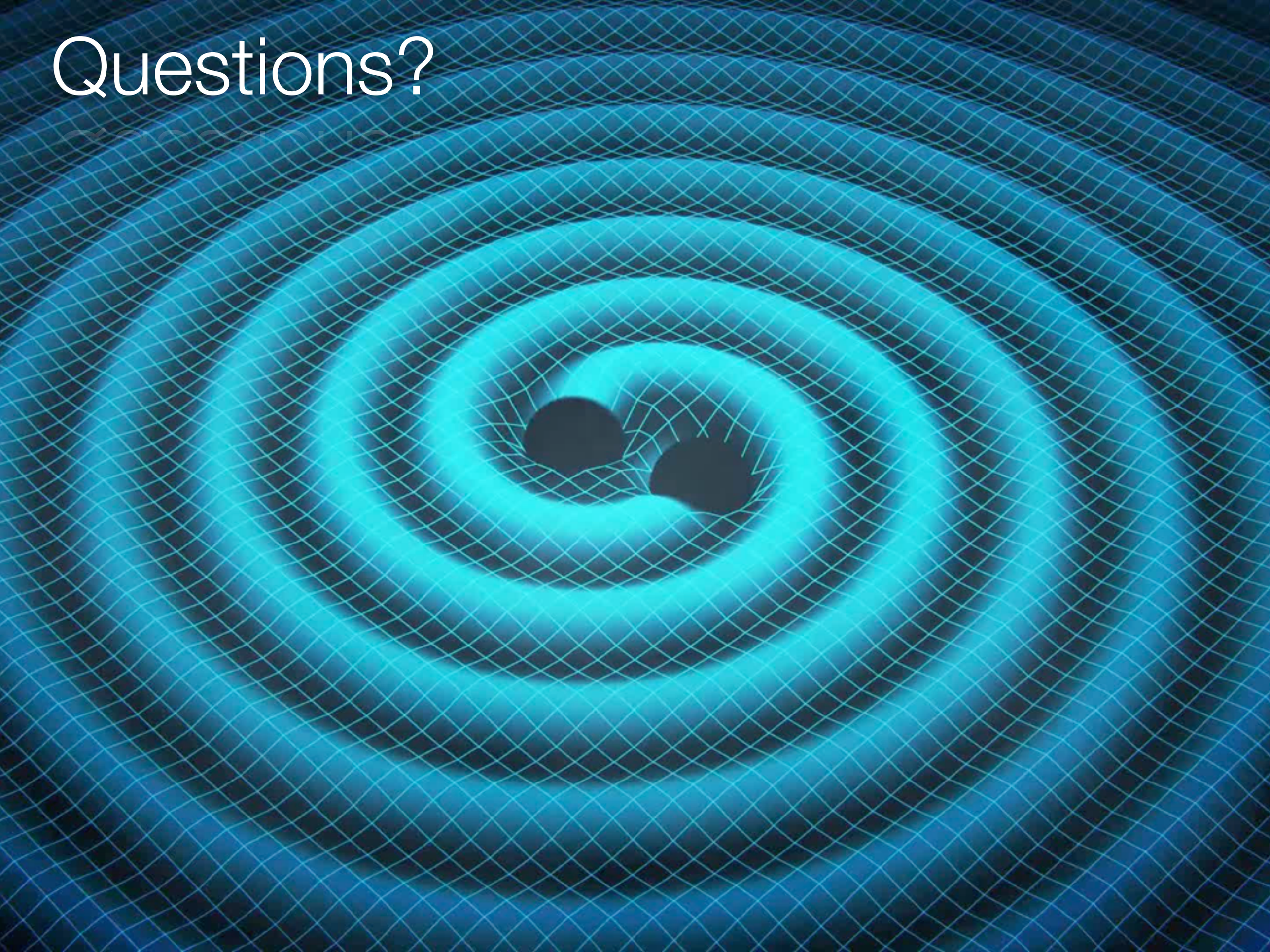
MORE INFORMATION

Craig Cahillane: calibration uncertainty during O2

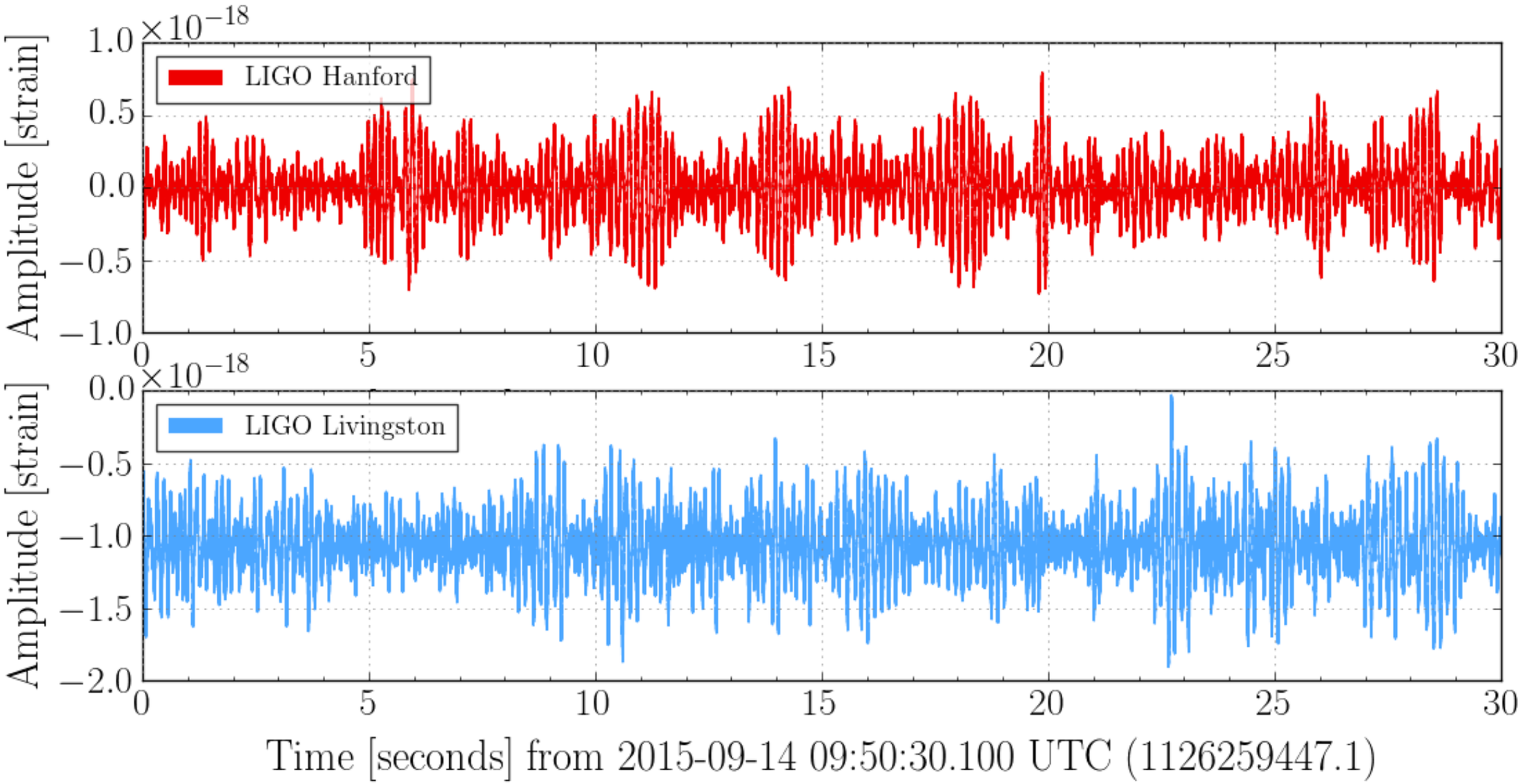
Shreya Anand: effects of calibration errors on sky localization

Questions?



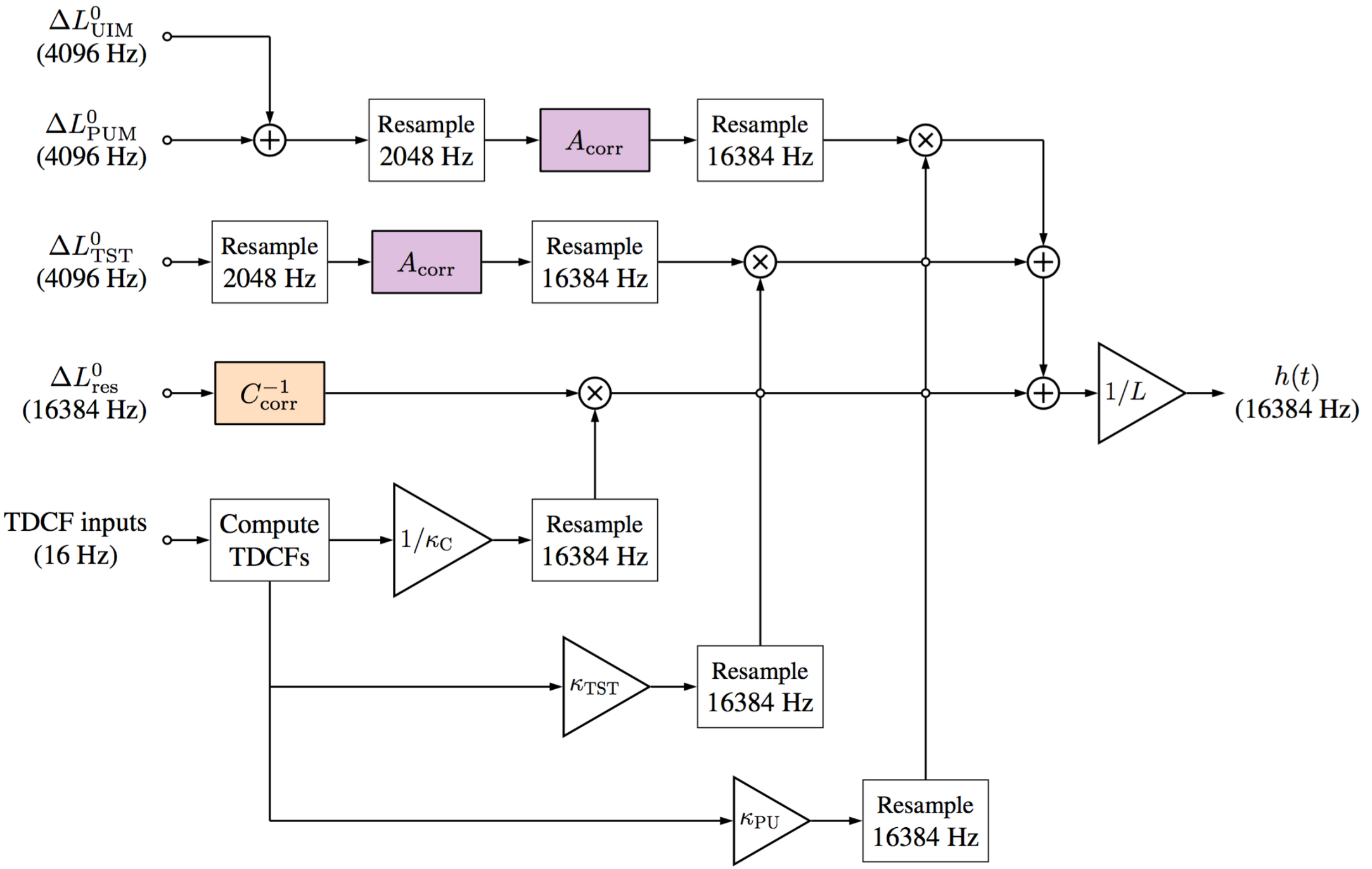
EXTRA SLIDES

Calibrated Strain

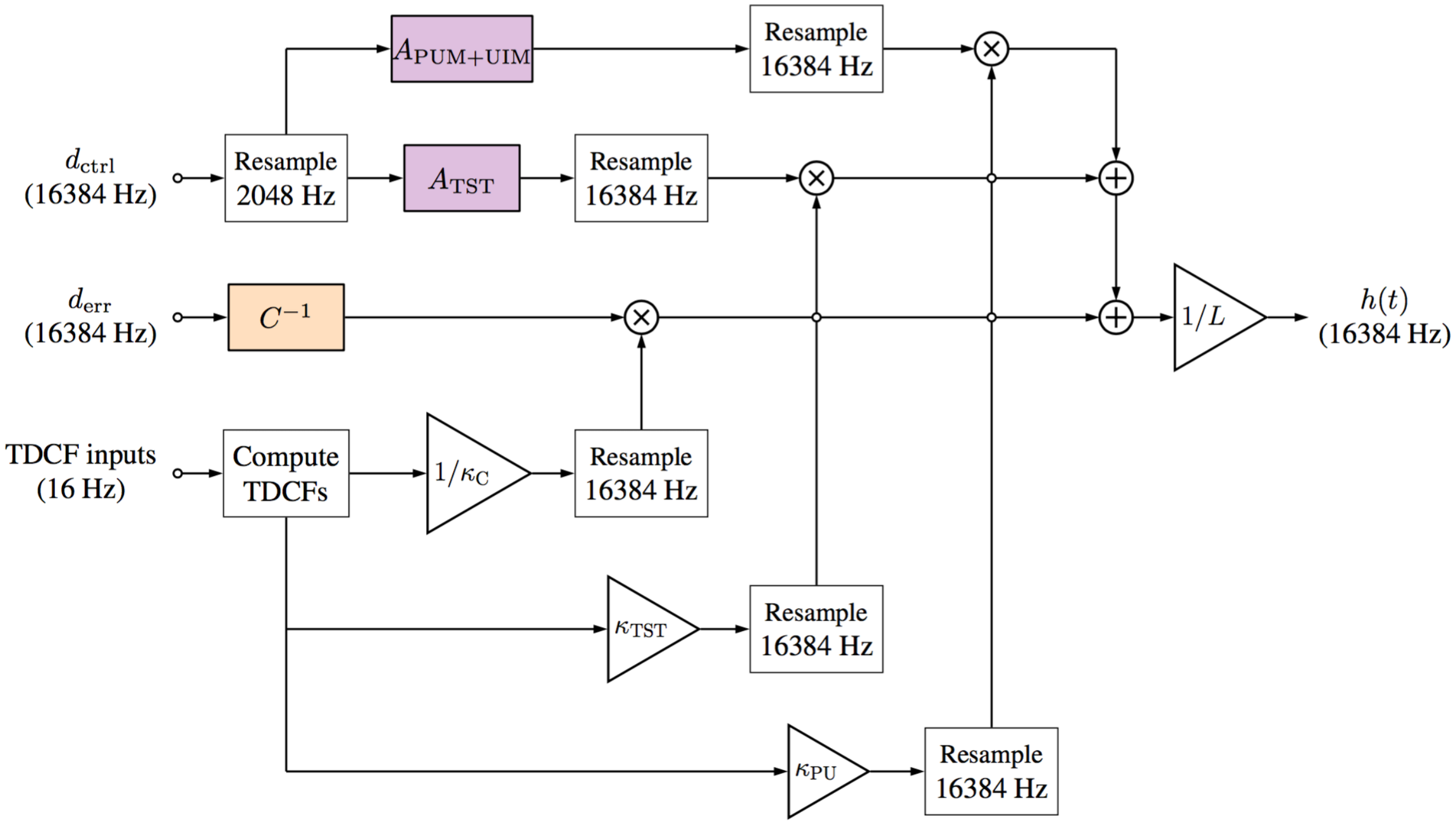


raw timeseries output can have DC offset, must be bandpassed (and notched) to visualize signals

Online Pipeline



Offline Pipeline



LIGO Data Grid

Data stored on computer clusters at Caltech, LIGO Hanford, LIGO Livingston, UW-Milwaukee, Syracuse, MIT, Cardiff, AEI Hannover, and AEI Berlin