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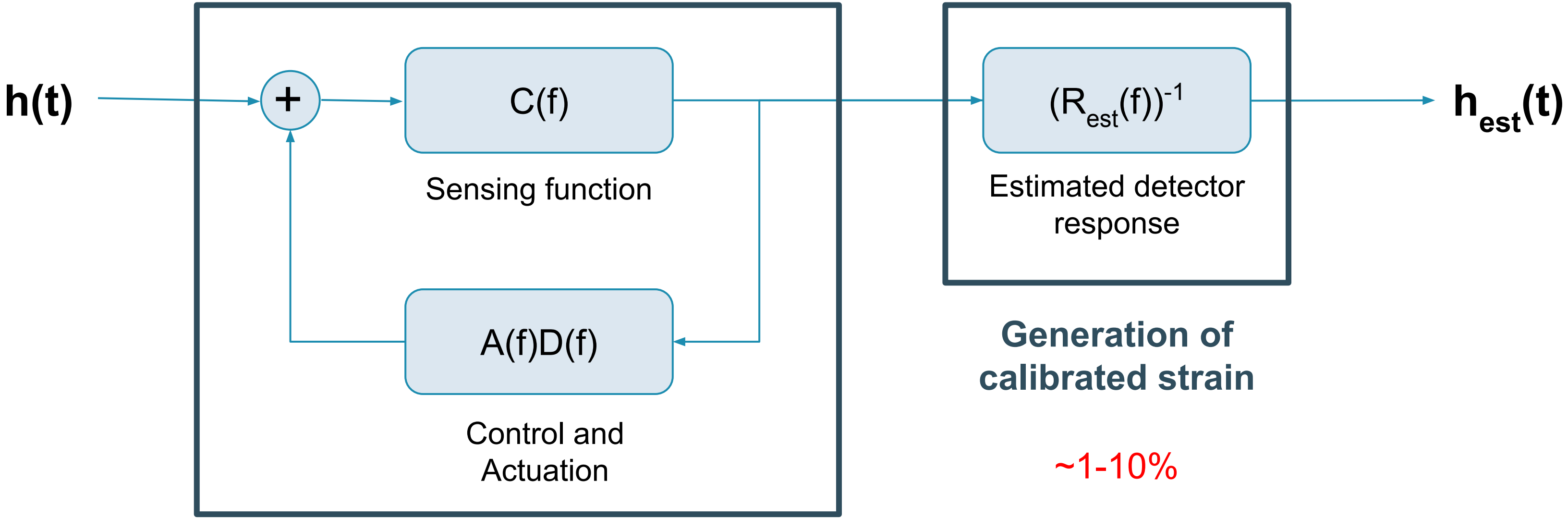
Impact of Physically Motivated Calibration Errors on Core-Collapse Supernova Searches

Milan Wils (KUL), Brad Ratto (UCSD), Michele Zanolin (ERAU), Marek Szczepańczyk (UF), Jeffrey Kissel (LHO), Gabriele Vedovato (INFN), Tjonnie G. F. Li (KUL)

Goal of the project

Calibration Uncertainty



Real-time detector control

~1-10%

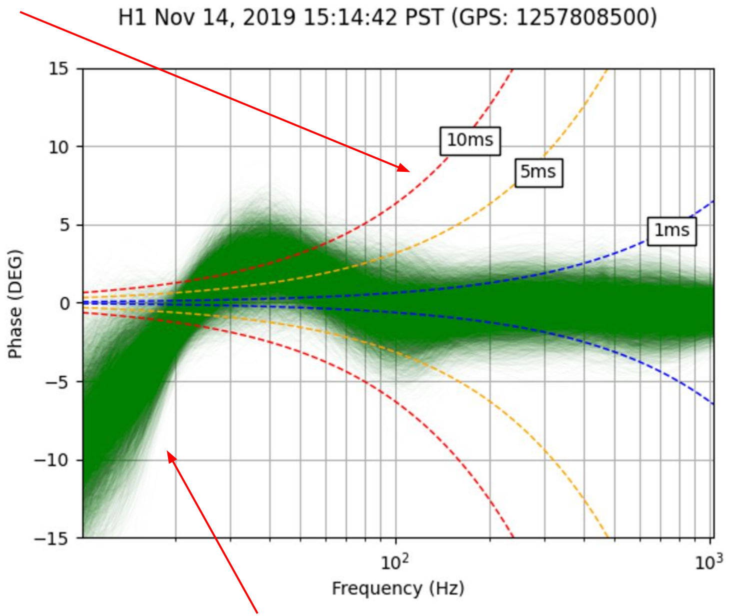
Impact on unmodeled search pipelines

- Calibration Error (CE) is different in each detector
  - Fraction of the signal is no longer coherent
  - Roughly proportional to the CE
- 2G detectors
  - SNR of detected events < 40
  - For CE < 10%: incoherent signal has SNR < 4
  - Low impact expected
- 3G detectors
  - SNR ~ 100
  - Residual signal no longer consistent with the noise

Old Method

- Calibration Error (CE) modelling
  - Amplitude scaling
  - Time jittering
  - Good approximation for narrowband signals
- Does not correspond to physical CEs

Frequency dependence of time jittering



Measured frequency dependence of phase CEs (smoothed by Gaussian Process Regression (GPR))

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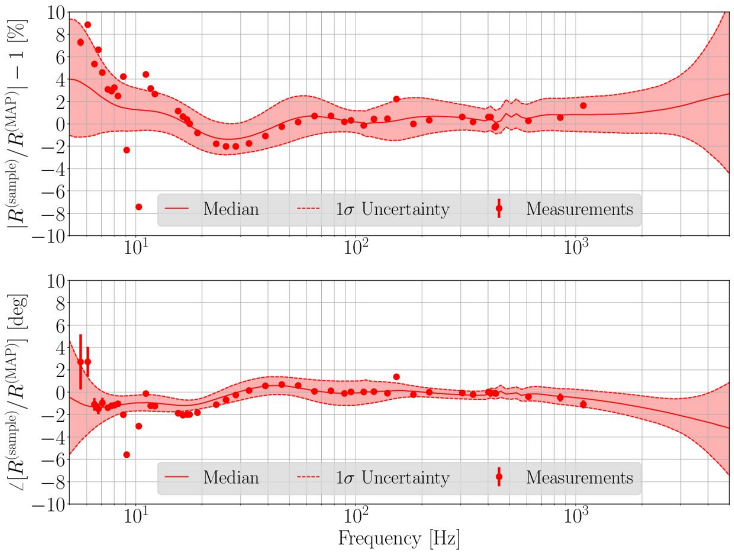
Goals

- **Method**
  - Apply physical CEs from uncertainty estimates
- **Measure impact**
  - coherent WaveBurst (cWB) detection statistics
  - Detection efficiency
  - Receiver Operator Characteristic (ROC) curve
  - With GPR the impact was negligible in the O3 targeted CCSN search (arXiv:2305.16146)
- **Unsmoothed calibration curves**
  - Re-run O3 analysis with curves that are not affected by GPR



Source: Ling Sun et al 2020 Class. Quantum Grav. 37 225008

Current Status

Implementation

x(t) injections

Rectangular windowing

Zero padding

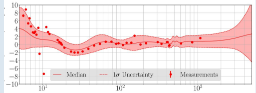
Single injection

(Weighted) Overlap Add

Miscalibrated injection

Re-inject

x'(t) injections



Draw a different CE curve for every interferometer (log spaced)

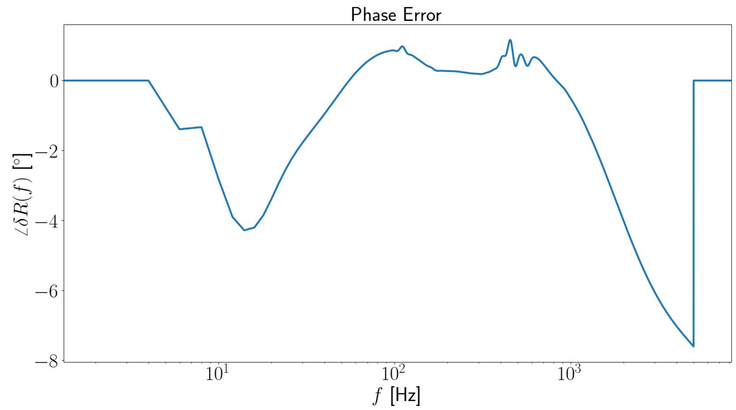
Cubic spline fit

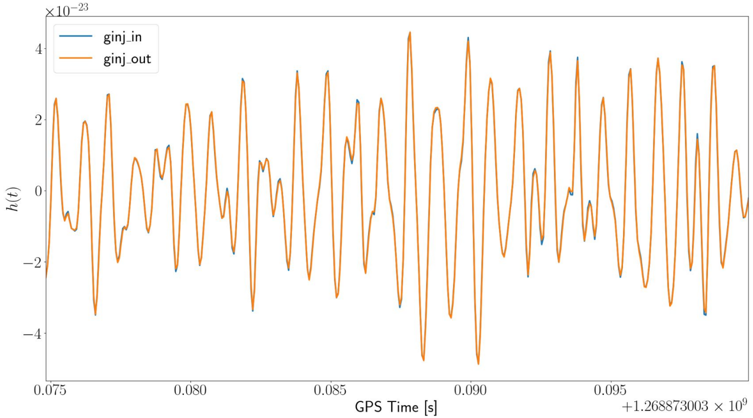
Sampling (linear spacing)

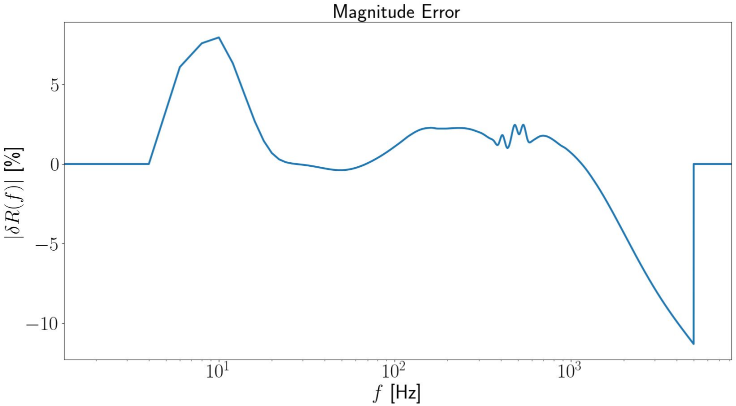
CE(f)

Example of Middle-of-the-Pack Error in O3 Data

- Waveform: mesa20_pert
- Draw from O3 H1 CE distribution
  - GPS: 1238047284

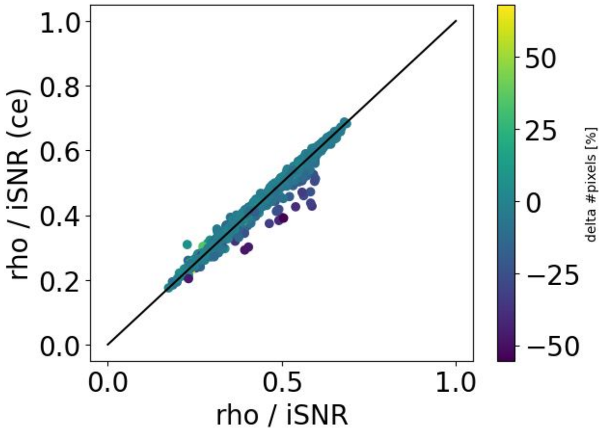


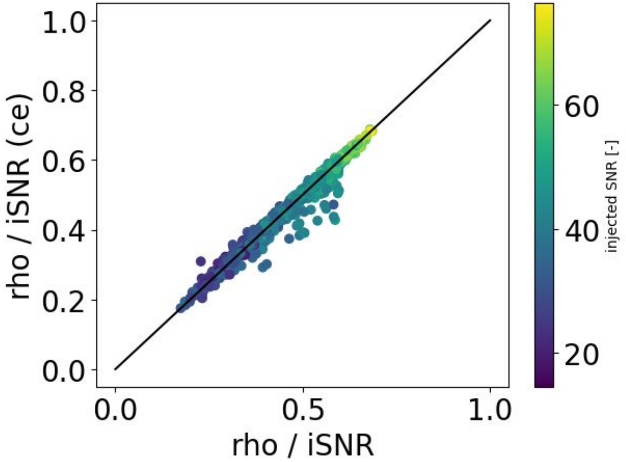




Worst Case Phase Errors

- mesa20 waveform at 420 pc
- Medium SNR (~40)
  - Most triggers unaffected
  - A few triggers have a loss up to 10%
  - Big difference in #pixels
  - Most likely some clusters of pixels are around a threshold value





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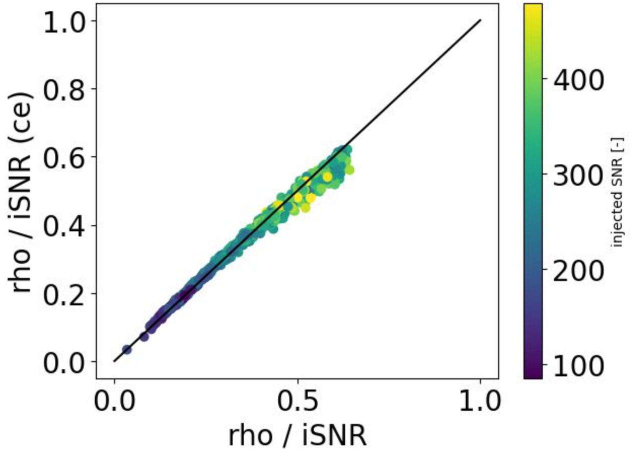
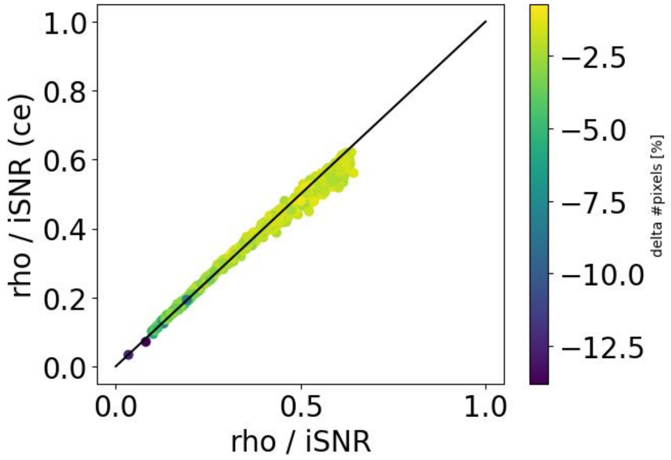
Worst Case Phase Errors

- s14 waveform at 30 pc
- High SNR (~200)
  - #pixels barely changes
  - Residual signal too small to affect likelihood / noise power
- Extremely high SNR (~400)
  - Only the coherent portion of the signal is detected
  - Residual signal becomes comparable to the noise

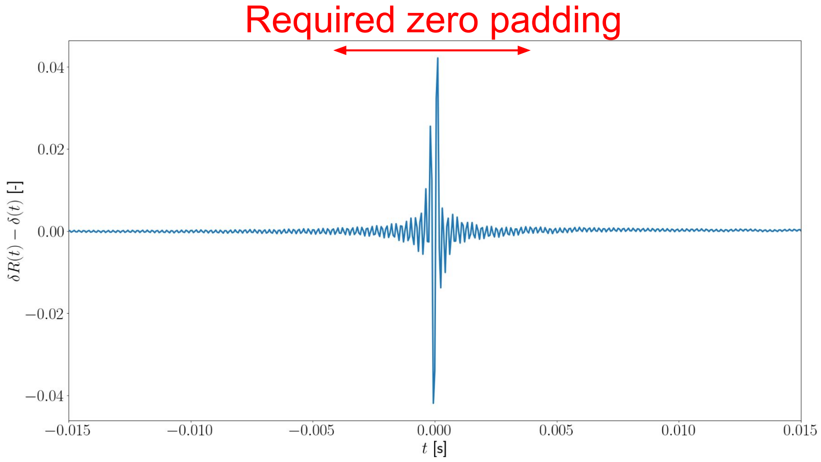


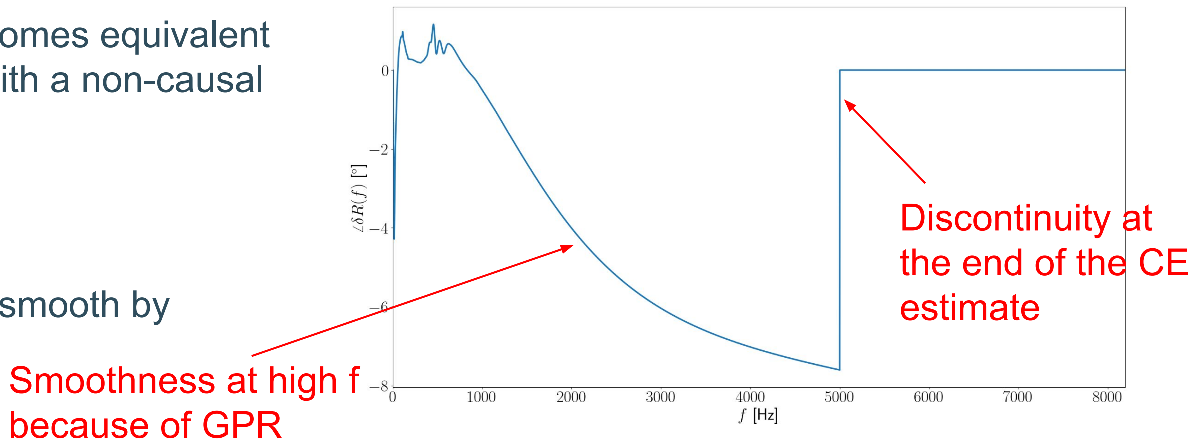


Open Issues

Signal Processing Artefacts

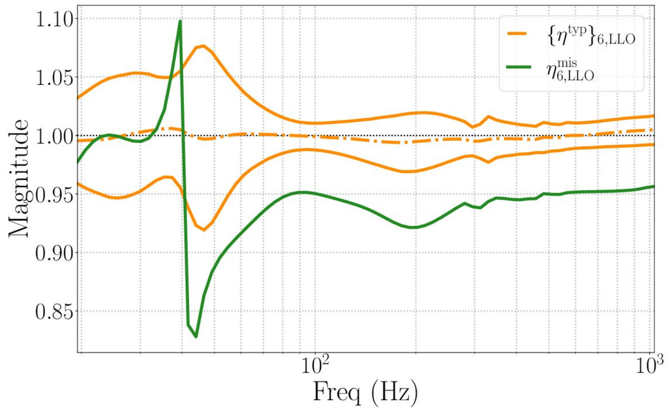
- Multiplication with CE in the Frequency Domain (FD) corresponds to a circular convolution in the Time Domain (TD)
- If TD zero padding is larger than non-zero part of the *Impulse Response* (IR):
  - Circular convolution becomes equivalent to a linear convolution with a non-causal finite IR filter
  - Removes artefacts
- Requires smooth CE curves
  - Can be made arbitrarily smooth by increasing the FFT size





Open Issues we are checking

- Sharp features in CE(f) are not simulated
  - Smoothness requirement on CE(f)
    - Depends on DFT-size and zero-padding
    - Check should be implemented
  - Gaussian Process Regression
    - Logarithmic smoothness
    - $k\left(\log(f), \log(f')\right) = \gamma_1^2 + \gamma_2^2 \exp\left(-\frac{\left(\log(f)-\log(f')\right)^2}{2\ell^2}\right)$



Huang et al. 2022, arXiv:2204.03614

- Sharp features do exist
  - Switch between actuation and sensing function
  - Finite Impulse Response Filters (FIRs)

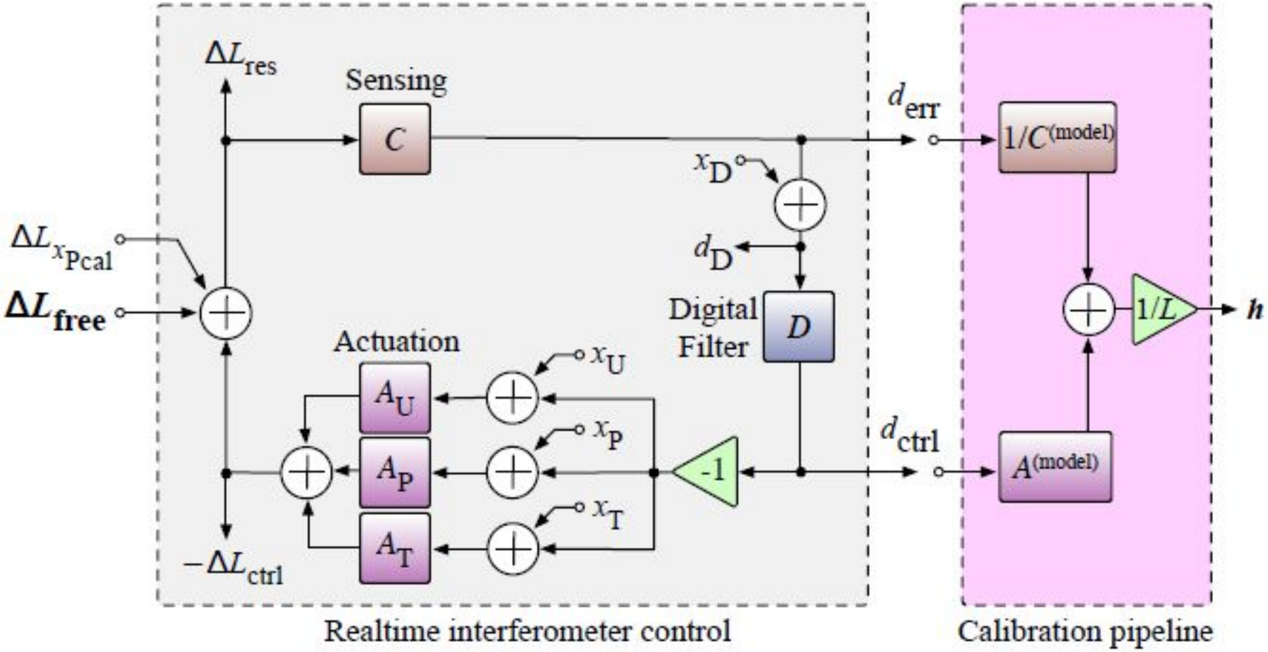
Conclusion

Conclusion

- Developed plugin for cWB that simulates **realistic** CEs
- Impact on detection statistics
    - Only significant effects are well above detection threshold (~10)
    - Increases false alarm probability
- Future work
    - Eliminate artefacts
    - Produce summary statistics (ROC, detection efficiency)
    - Include sharp features in the calibration error
    - Check the impact on parameter estimation

Backup slides

DARM Loop



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