Using adaptive filtering to track long-transient gravitational waves with varying frequency and amplitude

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Overview

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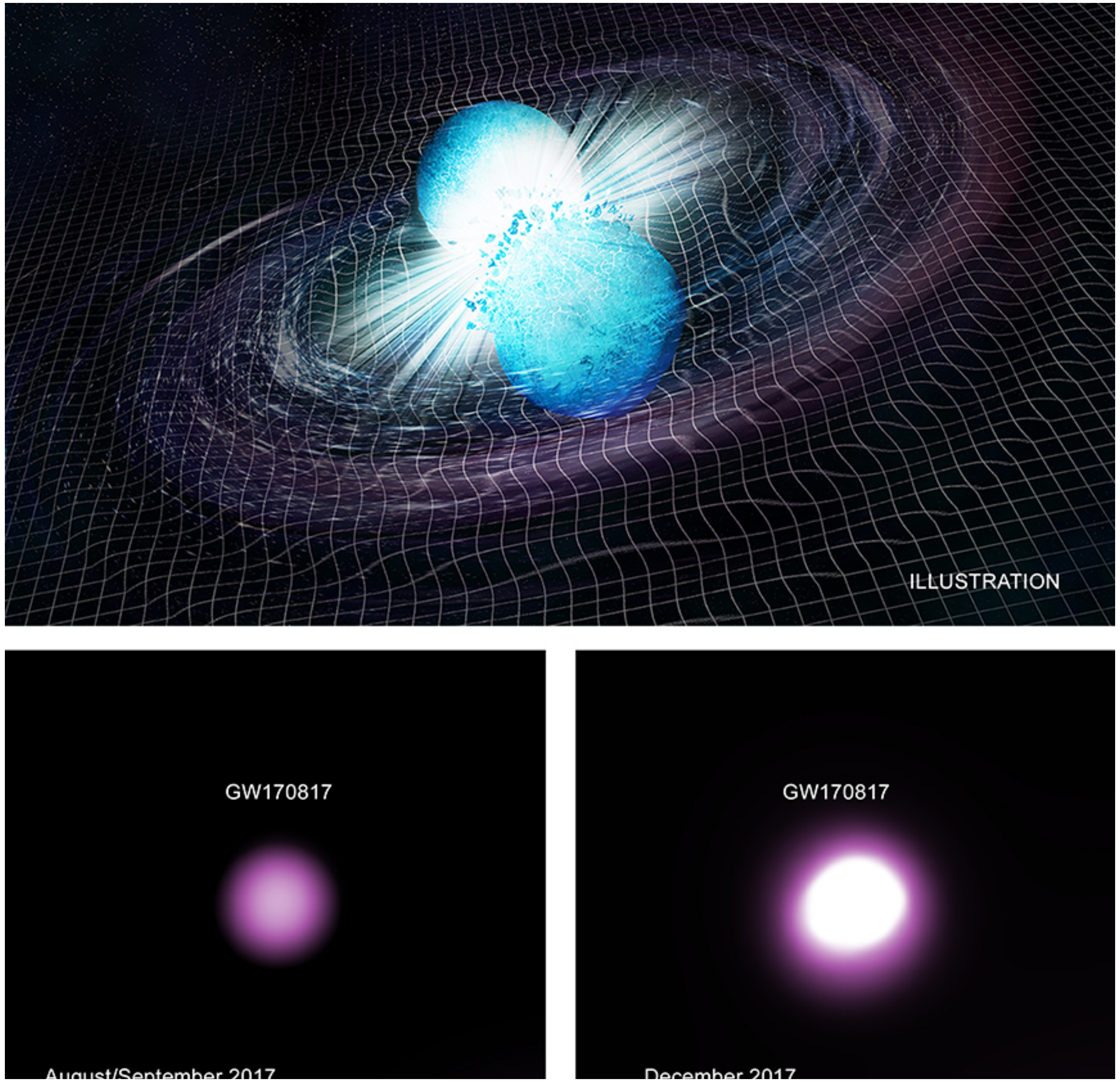
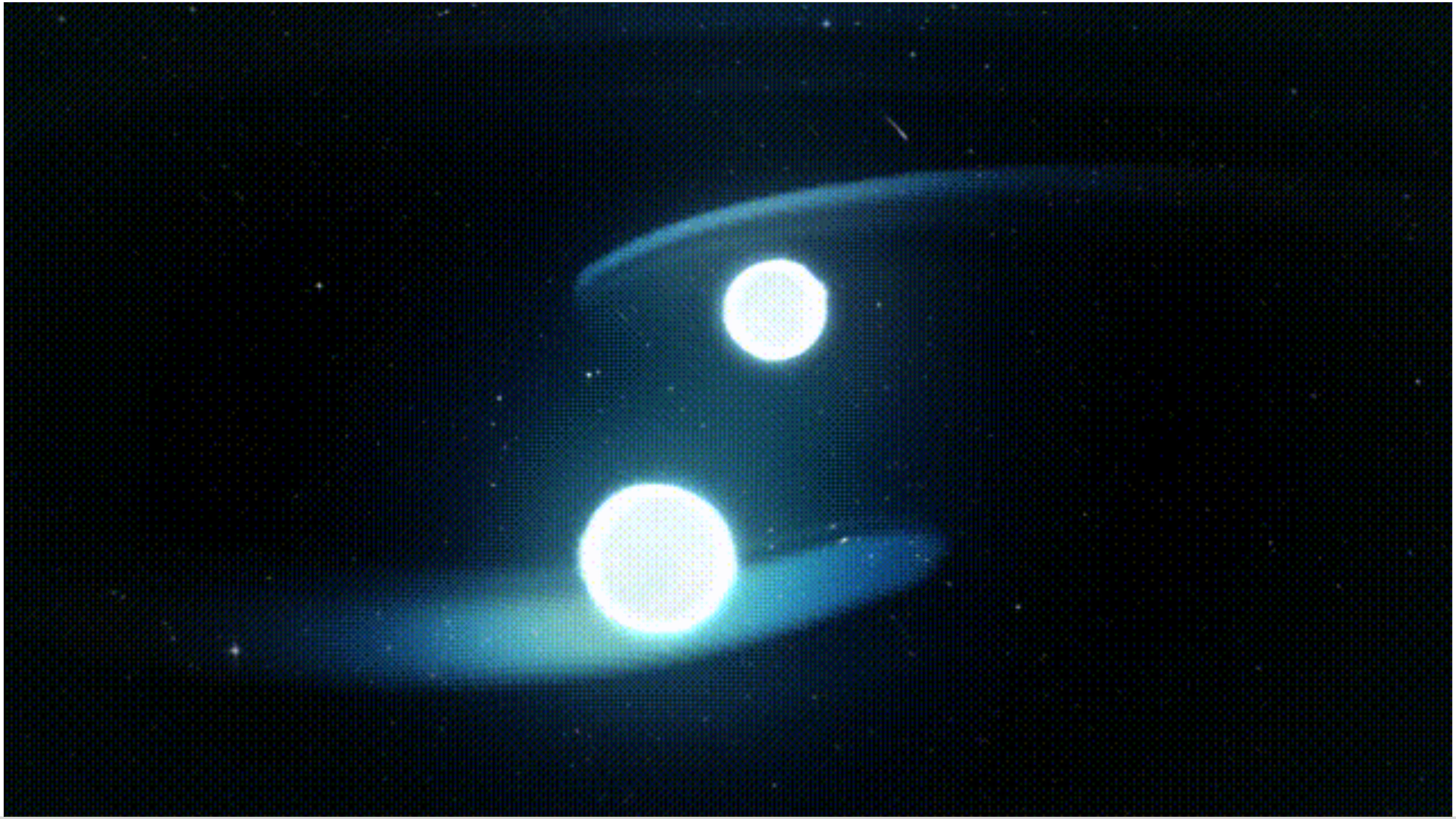
Introduction: Background/Motivation

- Compact Binary Coalescence (CBC) Gravitational Waves (GW)
    - 3 types: Binary Black Holes (BBH), Binary Neutron Star (BNS), and Neutron Star-Black Hole Binary (NSBH)
    - LIGO has detected 14 confirmed GW events, most of them being BBHs
        - 11 confirmed events in O1/O2
        - 3 confirmed events in O3 so far
    - During LIGO's 2nd observing run, BNS merger GW170817 was detected



Introduction: Background/Motivation (cont.)



Introduction: Background/Motivation (cont.)

- Binary neutron star postmerger remnants
  - The object created after a BNS causes a gravitational wave
  - Detecting postmerger remnant helps us understand more about what happens after the BNS collision and the Nuclear equation of state
  - Many publications trying to find remnant of GW170817
  - Postmerger remnant signals have not been detected

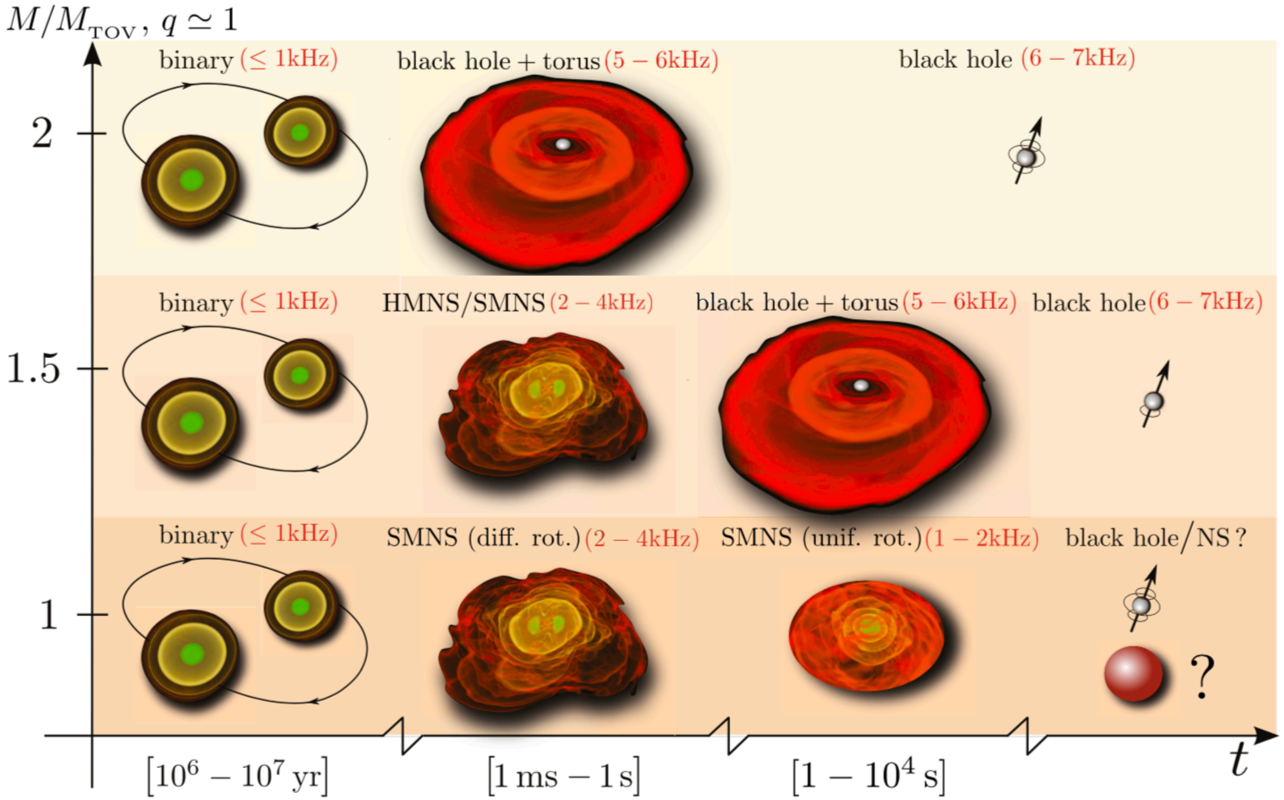


Image: Baiotti & Rezzolla (2017)

Introduction: Goals

- Part 1 – Explore the capability of iWave to track and detect weak long-transient GW signals like BNS post-merger remnants and quantify the sensitivity
- Part 2 – Track, study, and remove instrumental spectral lines from the interferometric data

Simulated Signal

- Models GW emission from a rapidly spinning-down millisecond magnetar born after the BNS merger happens at t=0
- Frequency calculated by:

$$f_{gw}(t) = f_{gw,0}\left(1 + \frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

- Amplitude calculated by:

$$h_0(t) = \frac{4\pi^2 G}{c^4}\frac{I_{zz}\epsilon}{d} f_{gw}^2(t)$$

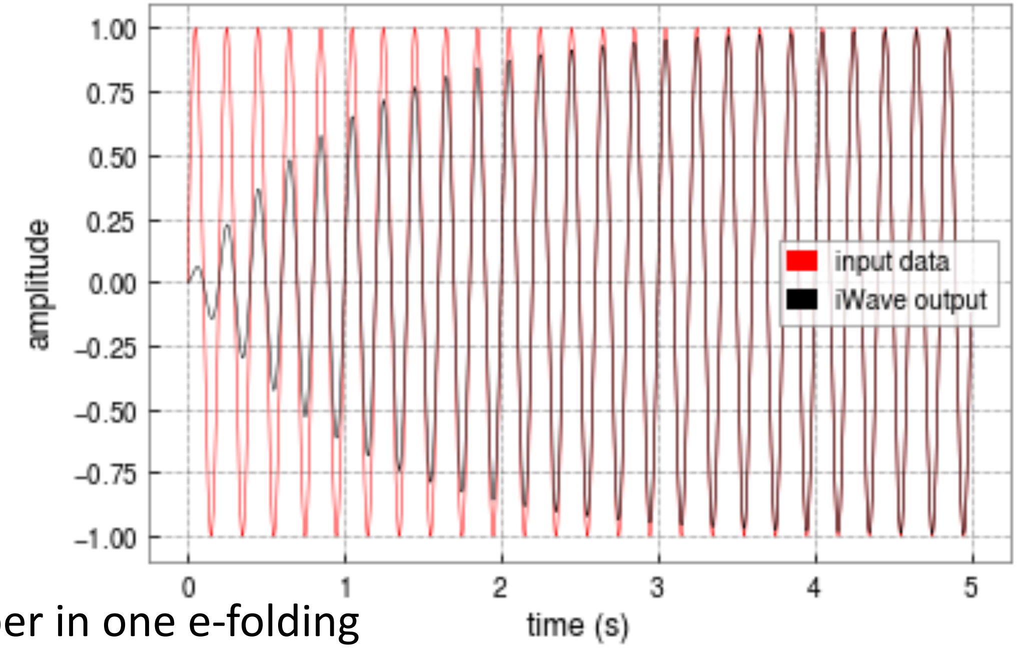
Parameters:

- $f_{gw,0}$ = initial frequency (Hz)
- t = time array (s)
- τ = spindown timescale (s)
- n = breaking index
- I_{zz} = principal moment of inertia (g*cm^2)
- ϵ = ellipticity of the star
- d = distance to the source (Mpc)

Methods: What is iWave?

- Hybrid method of a traditional phase locked loop (PLL) and an adaptive filter
- Traditional PLL that replaces the reference oscillator with an adaptive filter
- iWave characterizes the oscillating input x_n through the output y_n in this iteration equation:

$$y_n = e^{-w} e^{i\Delta} y_{n-1} + (1 - e^{-w}) x_n$$



Parameters:

- $\frac{1}{w}$ = sample number in one e-folding relative to the previous samples
- Δ = freq. in radians per sample
- y_{n-1} = previous output

Methods: Simulation Parameters

Parameters used to test iWave:

- $f_{gw,0}$ = 2000 Hz
- t = optimal observing time with 10000 s being the maximum
- n = 5
- I_{zz} = 1.e45 g*cm^2
- ϵ = 0.01
- Detector ASD = 4e-24 1/√Hz
- Only testing in a single detector

Frequency calculated by:

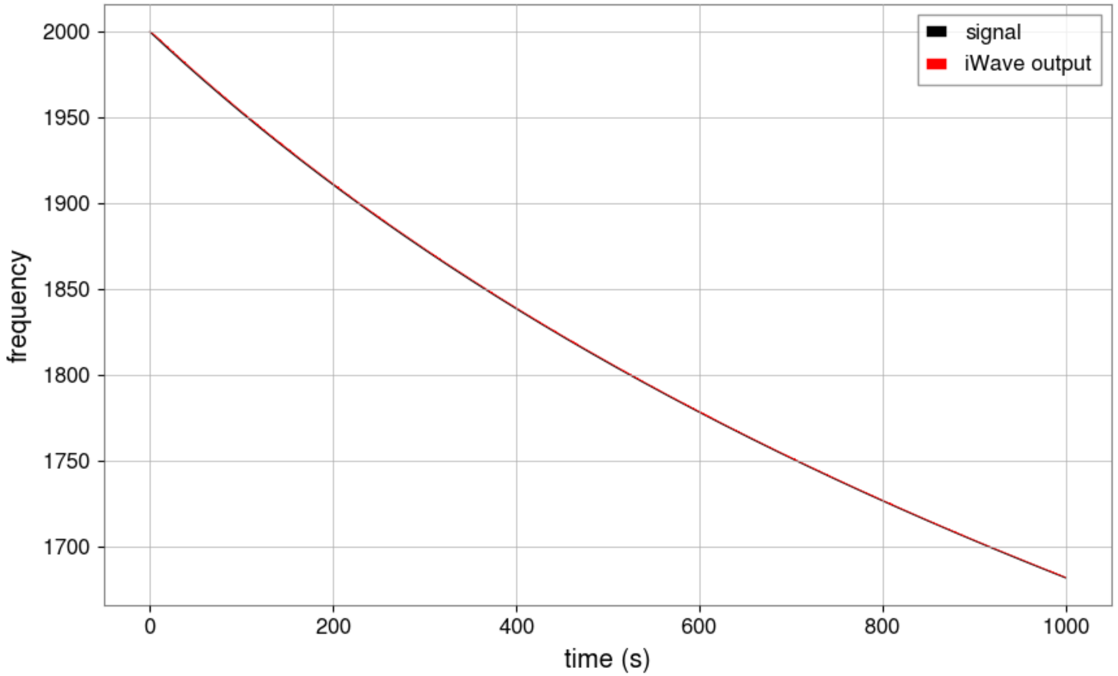
$$f_{gw}(t) = f_{gw,0}\left(1 + \frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

Amplitude calculated by:

$$h_0(t) = \frac{4\pi^2 G}{c^4}\frac{I_{zz}\epsilon}{d} f_{gw}^2(t)$$

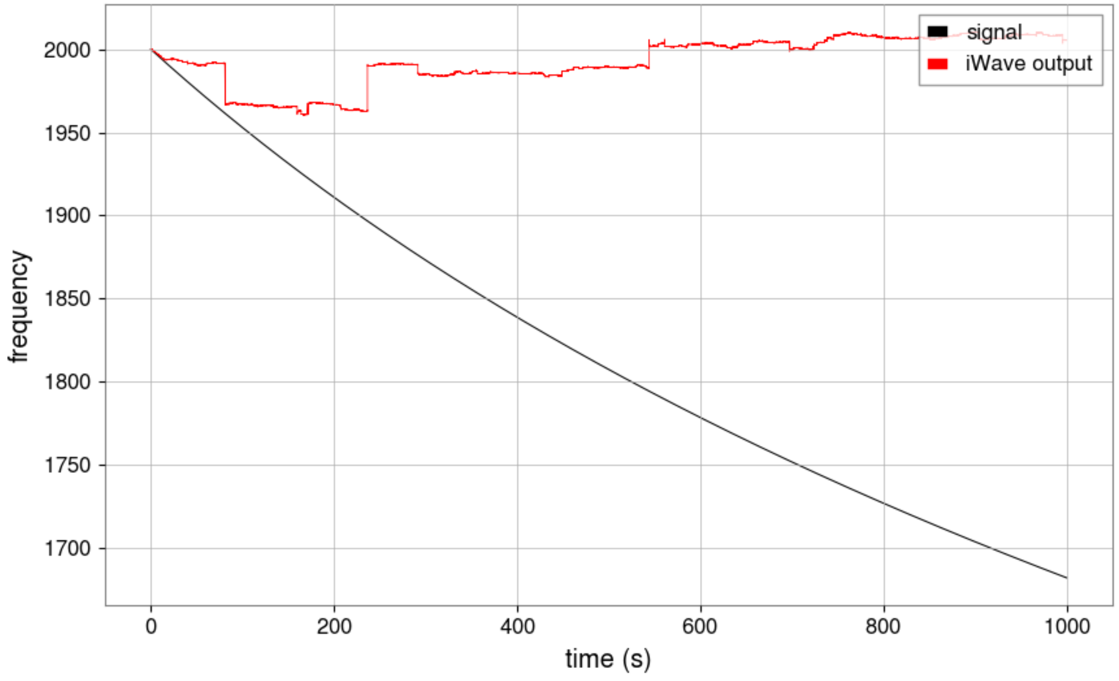
Results: iWave's Tracking Abilities

- Simulate waveform at different distances from the detector so the signal will be at different amplitudes once it reaches the detector
- d = 1 Mpc
- τ = 1000 s
- iWave locks onto the signal frequency



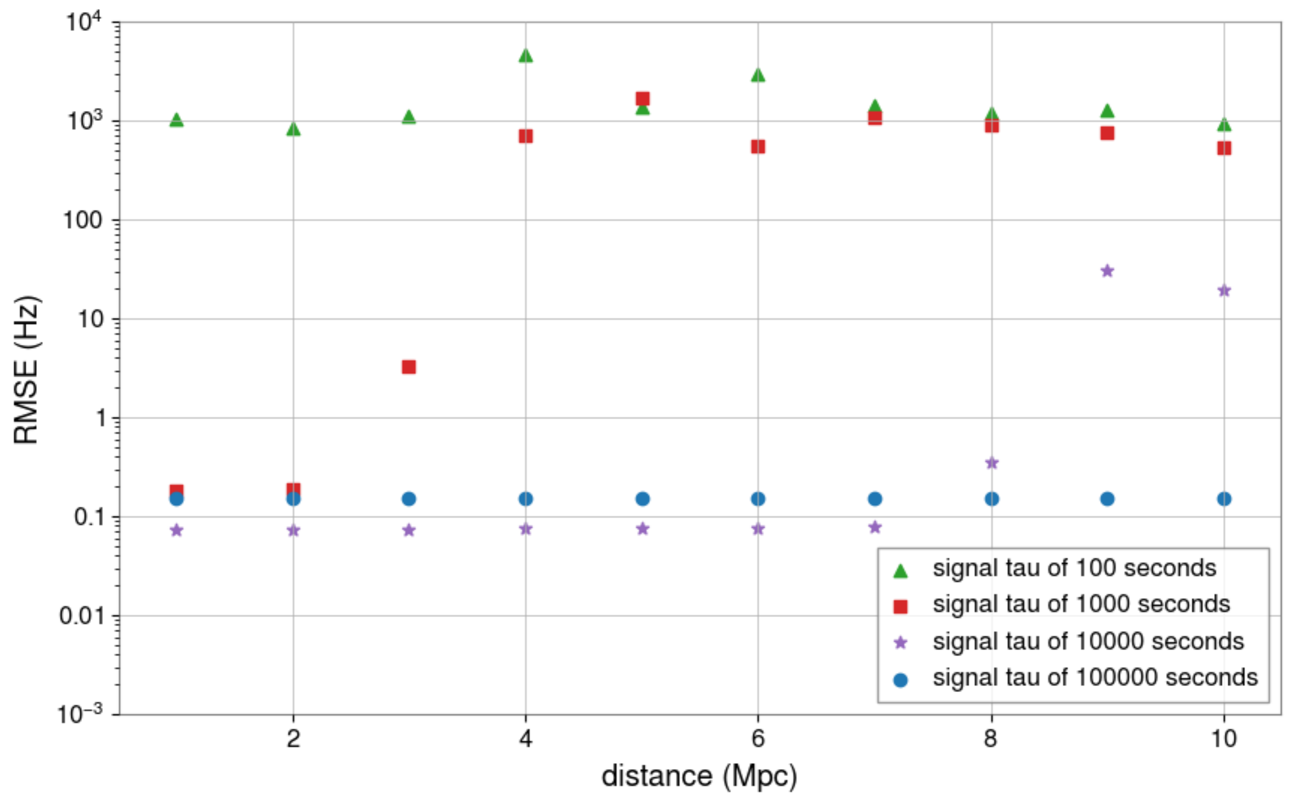
Results: iWave's Tracking Abilities (cont.)

- d = 4 Mpc
- τ = 1000 s
- iWave loses the signal part-way through the tracking
- As the freq. decreases, so does the amplitude



Results: Sensitivity of iWave

- 170817 was 40 Mpc away
- iWave is not sensitive enough to detect remnant from 170817
- Consistent with other studies

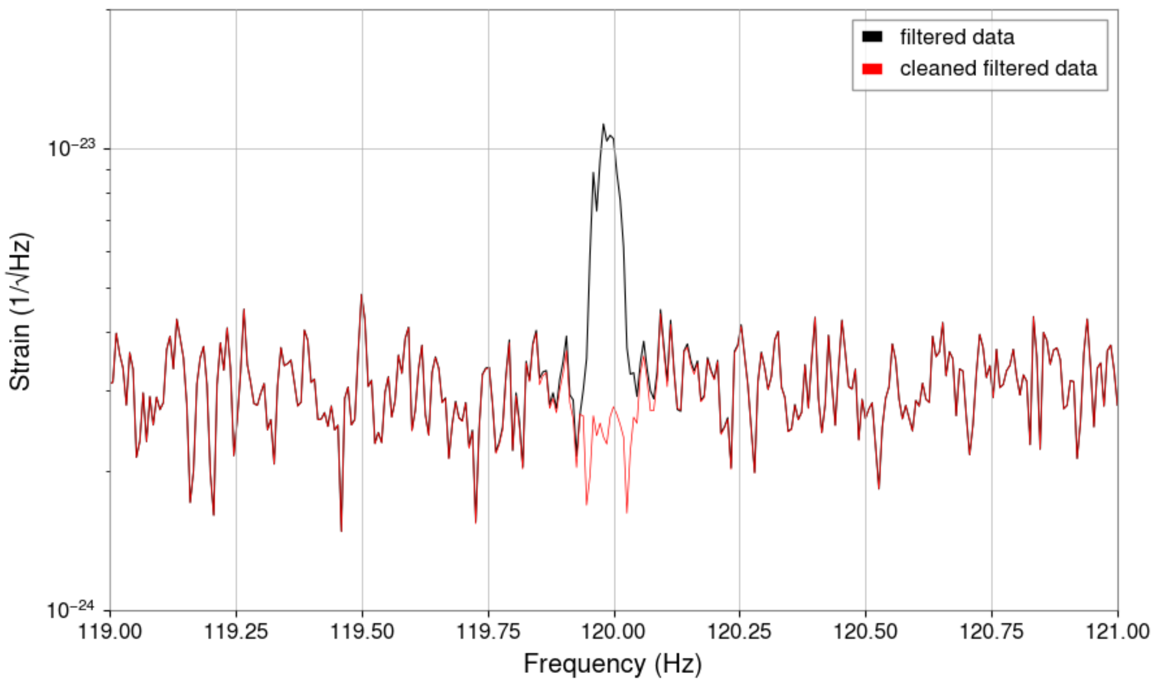


Conclusions/Future Work

- iWave is unable to track rapidly changing signals
- iWave is best at tracking signals that gradually change
- It can be applied to low-latency follow-ups of BNS postmerger remnant
- Can be used in preparation for future BNS events

Conclusions/Future Work (cont.)

- Still need to carry out more studies to test iWave's sensitivity to long-transient GW signals
- Part 2 – track, study, and remove instrumental spectral lines from the interferometric data
- Example: tracking/cleaning 120 Hz power main line



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