Approximating Simulated BBH SGWB with Broken Splines and Power Laws

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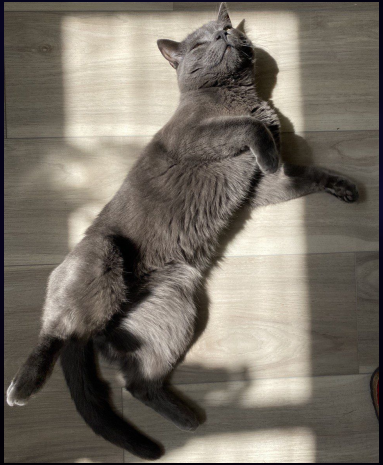
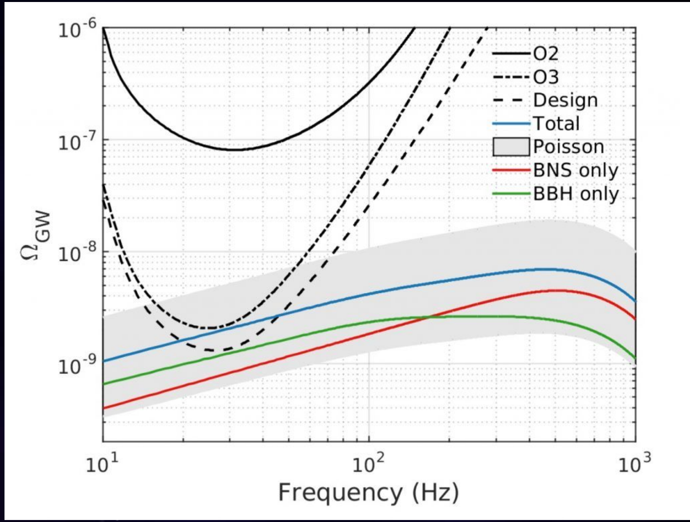
Overview

- SGWB
- RJMCMC Algorithm
- BBH Energy Density
- Recovering Parameters with RJMCMC
- Results
- Future Steps



What is SGWB?

- 4 primary sources of GWs:
  - CBCs → chirps
  - Pulsars → periodic GW emission
  - Supernovae → ???
  - SGWB
- Formal definition: “all unresolved sources of GWBs in the universe”
- Assumed isotropic, Gaussian, stationary, unpolarized
  - The longer we collect data, the more we can refine this background
- So far, lots of work on bounding the SGWB
- Detected as a power law for now, anticipate a turnover in more sensitive detectors



https://arxiv.org/pdf/1710.05837.pdf

BBH Background Energy Density

$$\Omega(f) = \frac{f}{\rho_c} \int dz \frac{\mathcal{R}(z) \langle \frac{dE}{df} |_{f(1+z)} \rangle}{(1+z)H(z)}$$

- Energy density spectrum dependent on SFR (star formation rate)
- R(z) encodes metallicity as a function of redshift
- (1+z) factor incorporates time delay
- Population averaged energy density depending on the two BBH masses

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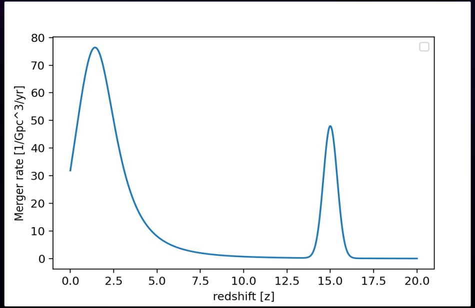
Merger Density Rate



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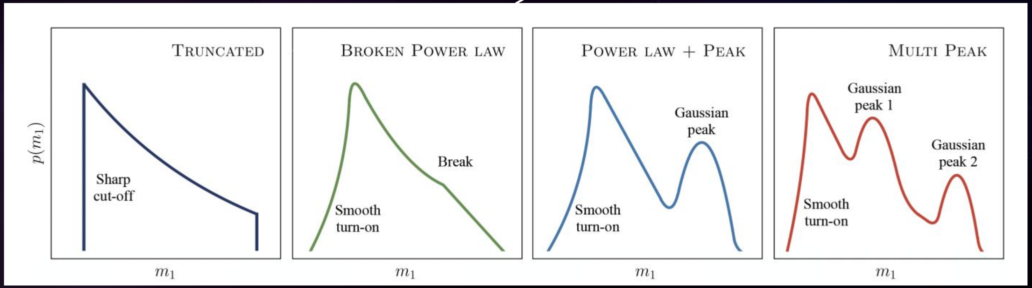
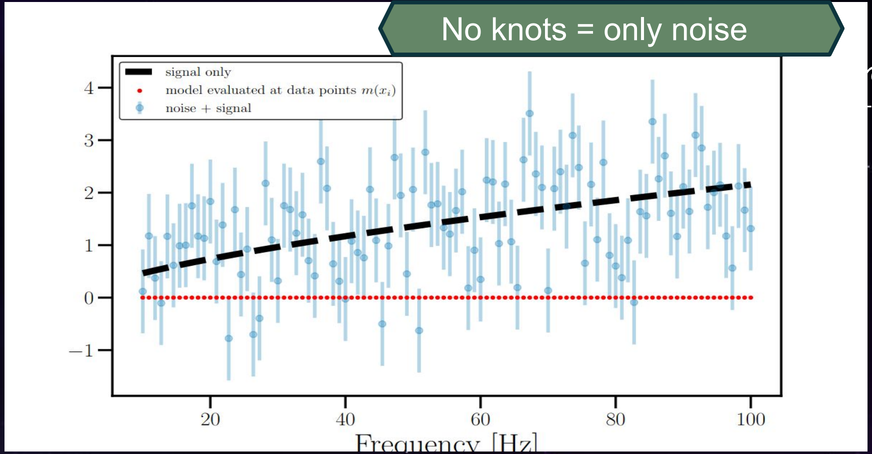
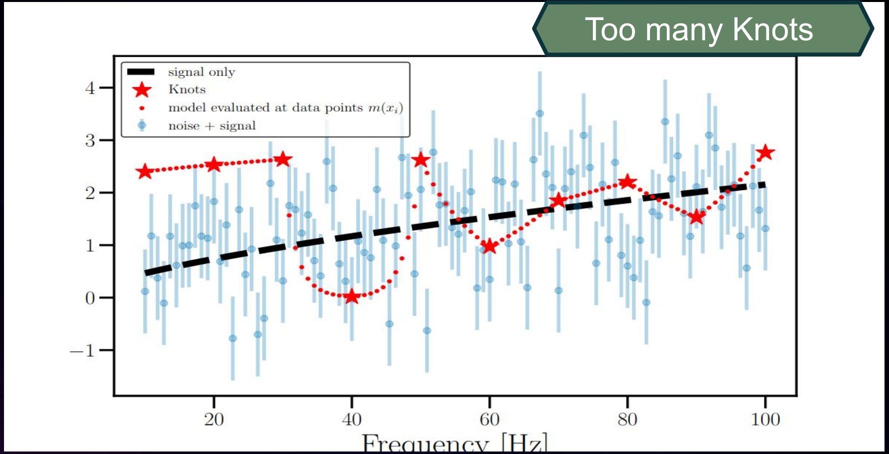
Population Averaged Energy Spectrum

Abbott, R., et al. (2021)

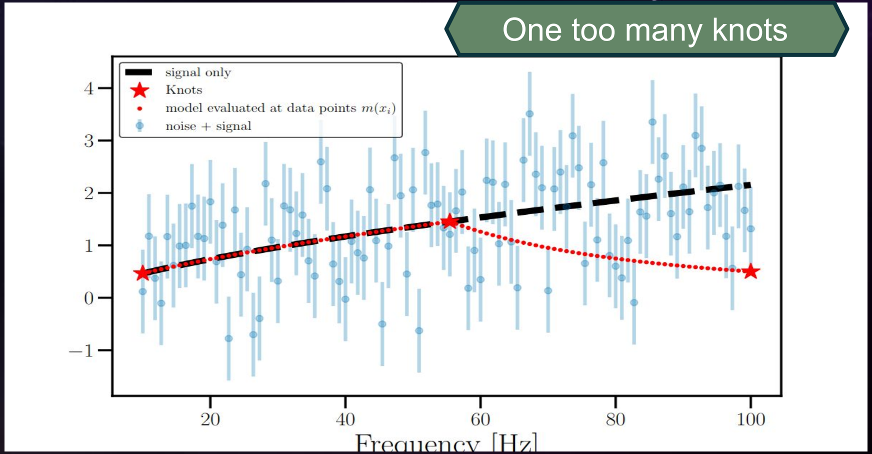




No knots = only noise
signal only
model evaluated at data points $m(x_i)$
noise + signal
Frequency [Hz]



Too many Knots
signal only
Knots
model evaluated at data points $m(x_i)$
noise + signal
Frequency [Hz]



One too many knots
signal only
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noise + signal
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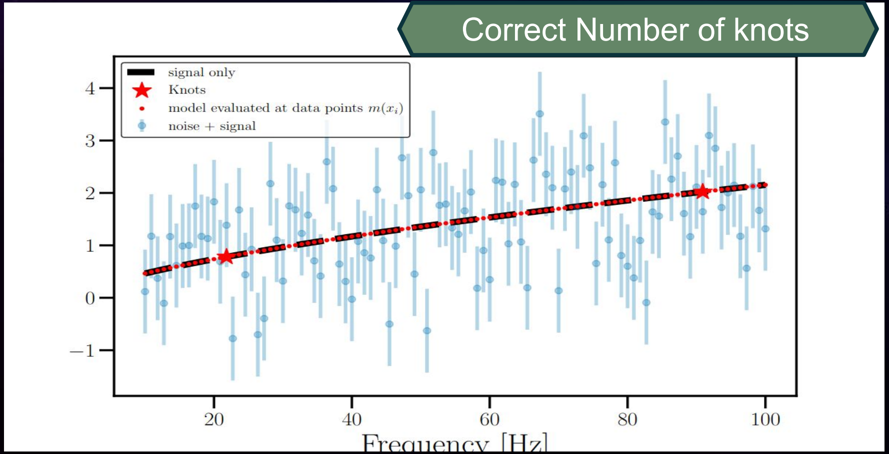
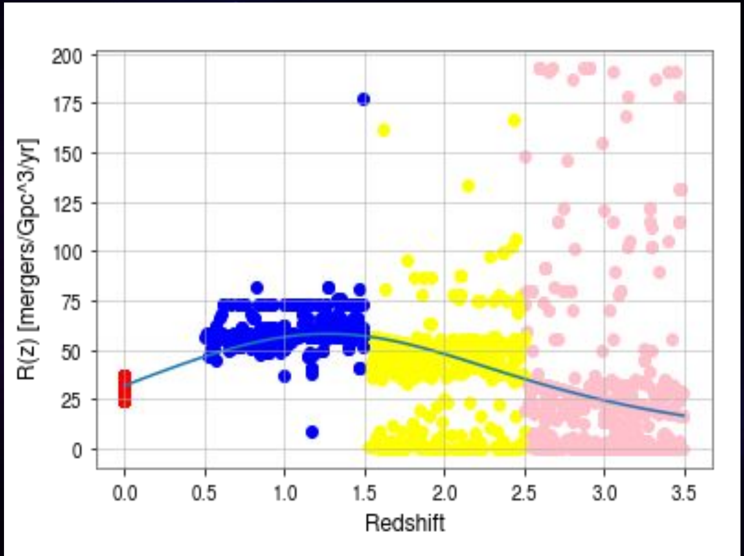


Correct Number of knots
signal only
Knots
model evaluated at data points $m(x_i)$
noise + signal
Frequency [Hz]

RJMCMC Fitting Algorithm

Markov Chain Monte Carlo (MCMC)

- Moving node horizontally + vertically
- Diagonal movement (differential evolution)
  - Scale a vector drawn between 2 random previous nodes



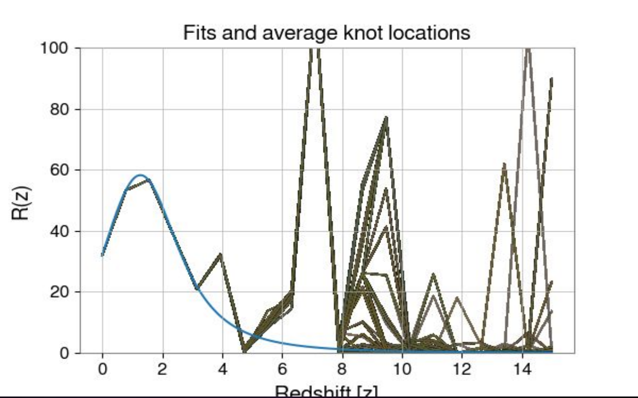
Reverse Jump (RJ)

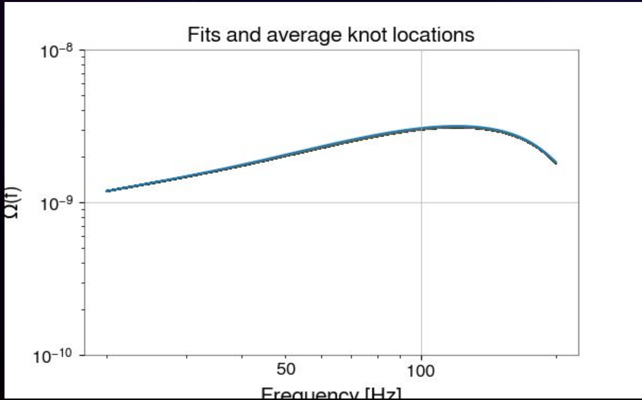
- Birth + death proposals
- Allows the algorithm to find the optimal number of nodes in a range

Recovering Parameters with RJMCMC

Can we recover parameters in a different space than our data?

- Finding the Omega(f) very well
- Spikes in higher redshift - RJMCMC finding that high redshift mergers don't contribute much to the energy density spectrum
  - Not much constraining that high redshift once the fitter gets stuck

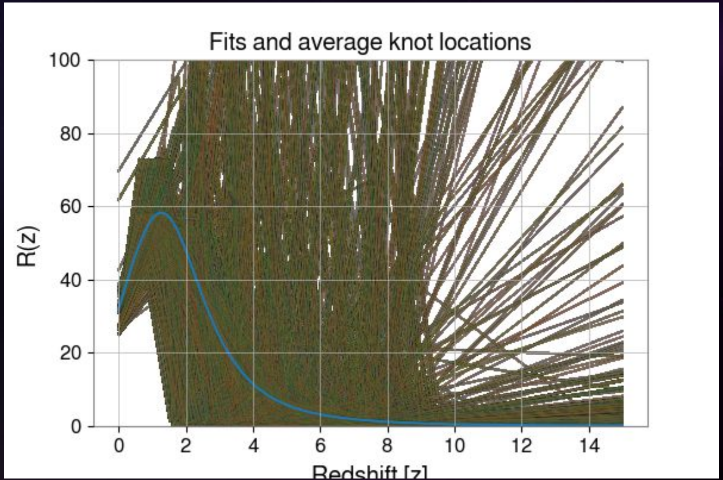


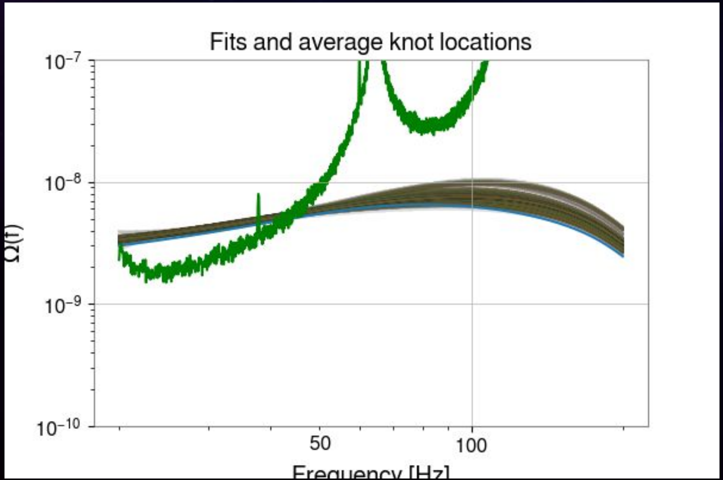


Let’s Get Noisy!

Given noise, can we still recover the profile in parameter space?

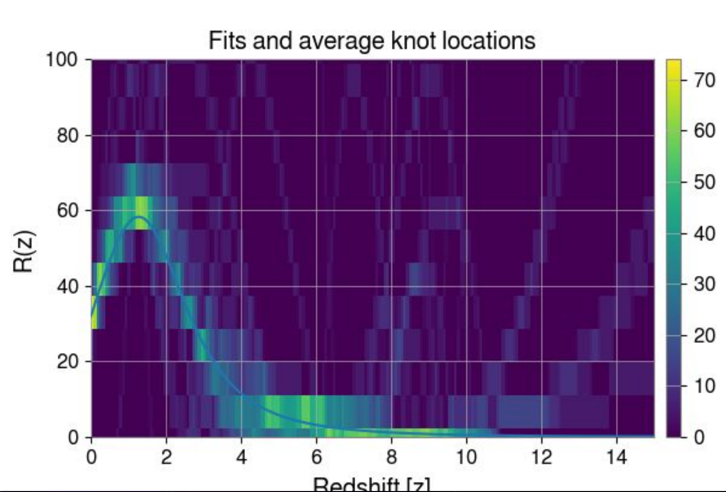
- Noise is green curve → larger than injected Omega(f)
- More variation in fits but evidence envelope of fits around injected R(z)

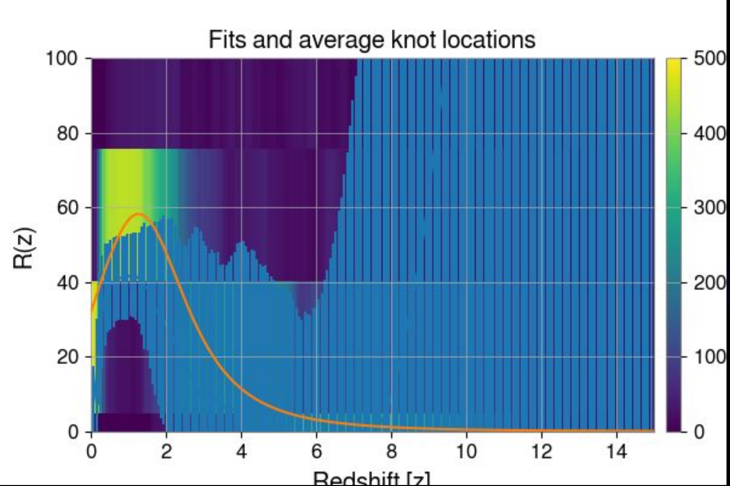




Results

- Recovering the injected R(z) within an envelope of 1σ given only Omega(f)
- Peak is located in the 1σ envelope of recovered fits with injection + significant noise
- Able to recover multiple R(z) injections
  - Requires more iterations (1 million)
  - Expected but confirmation is nice since we start the nodes on a guessed R(z) curve





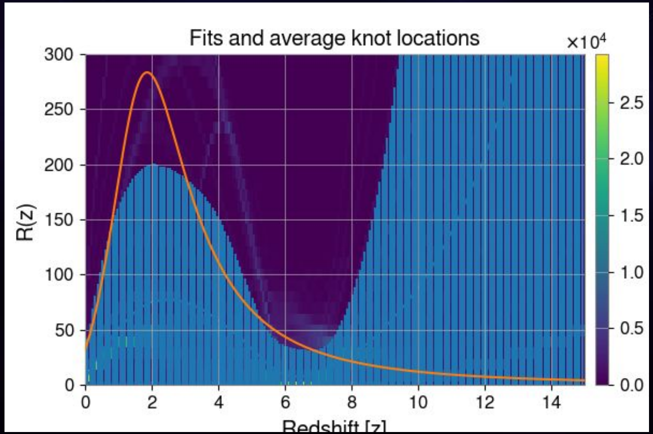
Bounding 3G Detectors

- Integrate over the fits to make histogram
- Must weight the integral by detector sensitivity

detector sensitivity

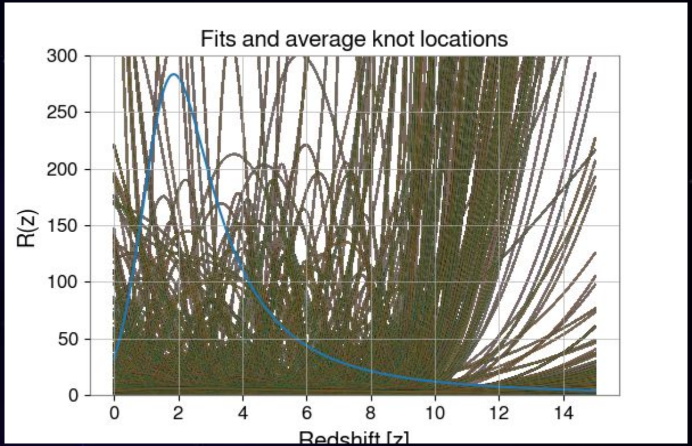
$$\int \left(\frac{dN}{dzdm}\right) dmdz = \int dmdz \frac{T_{obs}\mathcal{R}(z)\frac{dV}{dz}}{(1+z)} p(m) p(m,z)$$

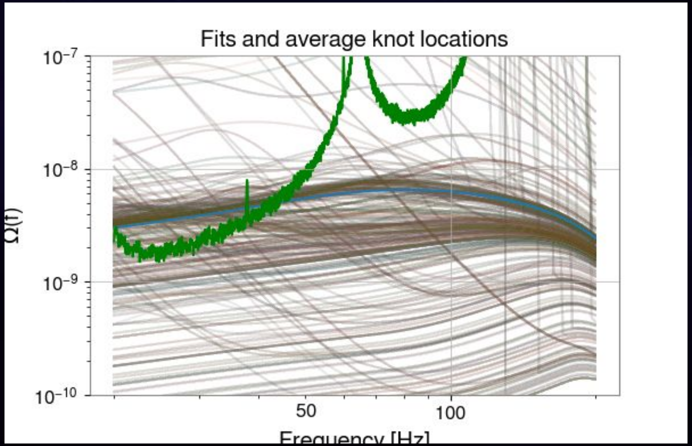
- Goal: apply this method to 3G detectors



Future Work

- Try recovering over parameters and profiles of GWB given Omega(f)
- Place nodes in Log(R(z)) space instead of just R(z)
- Take a step back and see if given a TimeSeries, what we can recover
- Add in better marginalization to more accurately predict 3G stellar BBHs
  - Run more iterations of the recovery to better converge
- Generalize and package this pipeline





Recap

- As our GW detectors get more sensitive, we want to be able to capture, fit, and understand the SGWB broken power law
- Westley - generalized RJMCMC fitter we anticipate will find Omega(f) features
- One application of Westley: fitting in parameter space
- Can recover parameter profiles even with noise in Omega(f) space
- Understanding and analyzing posterior R(z)s → bounding 3G detectors

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