Studying the Effects of Tidal Corrections on Parameter Estimation

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Outline

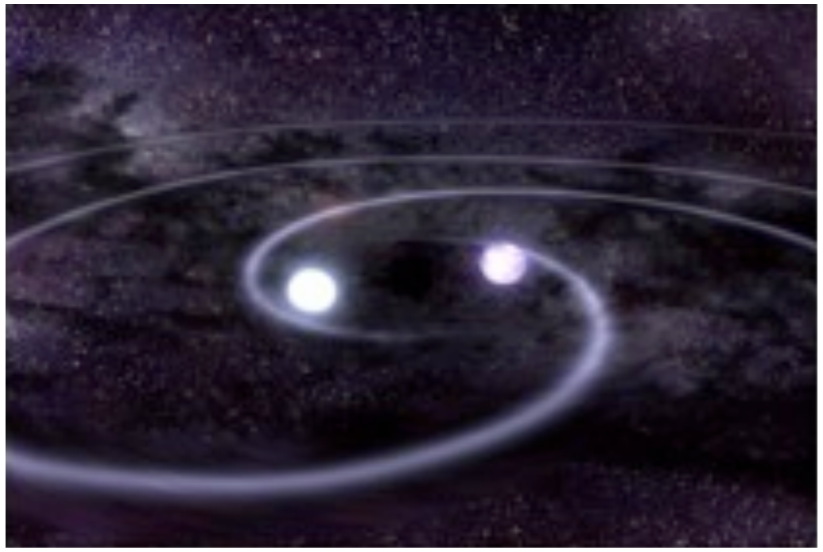
- Background: *Physical description of tidal forces*
- Motivation: *Constraining NS equation of state*
- Gravitational Waveform: *Mathematical description of tidal corrections*
- Previous Work: *Focus on Fisher matrix*
- Proposed Contribution: *Full Markov Chain Monte Carlo runs and understand systematic biases*
- Summary

Compact Binary Coalescence (CBC)

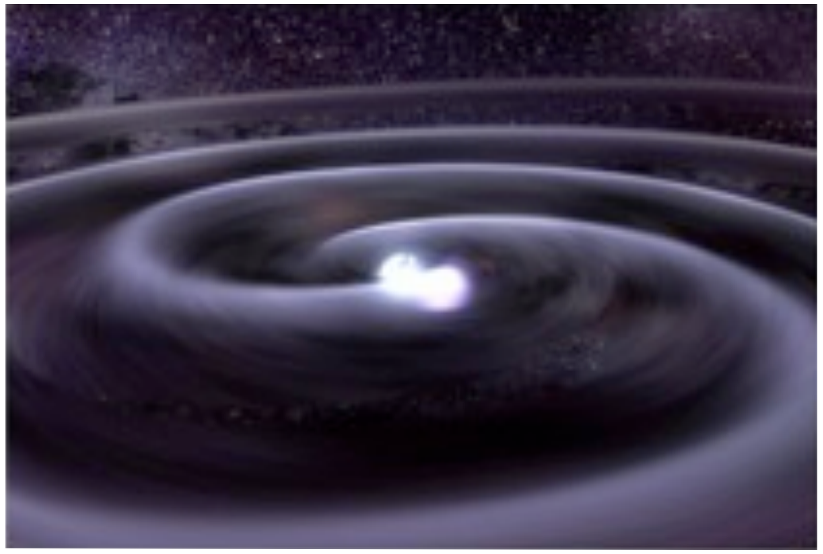
- When two massive bodies are in orbit, they will lose energy to gravitational-wave emission

- They will ***inspiral*** until ***merger***, which is followed by a ***ringdown***

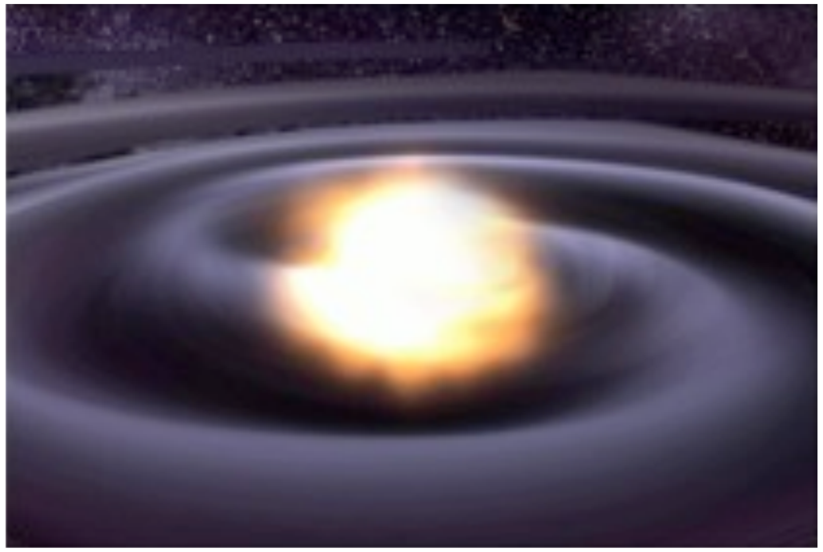
- The gravitational waveform of the CBC inspiral can be approximated using post-Newtonian theory



Inspiral



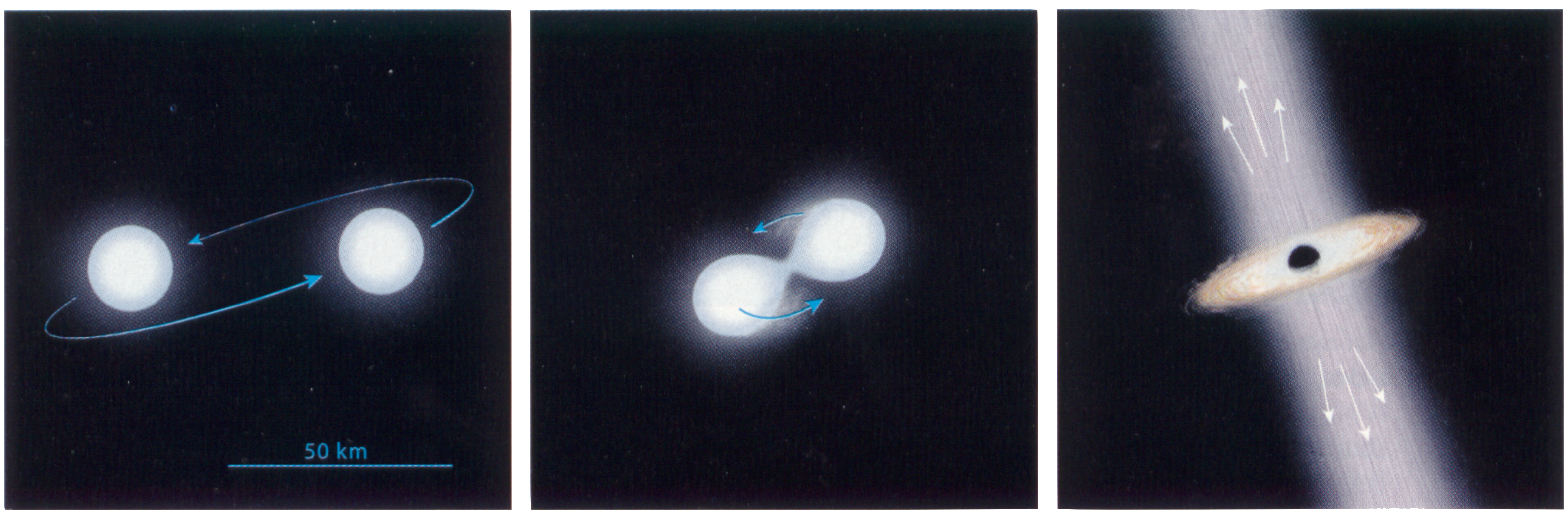
Merger



Ringdown

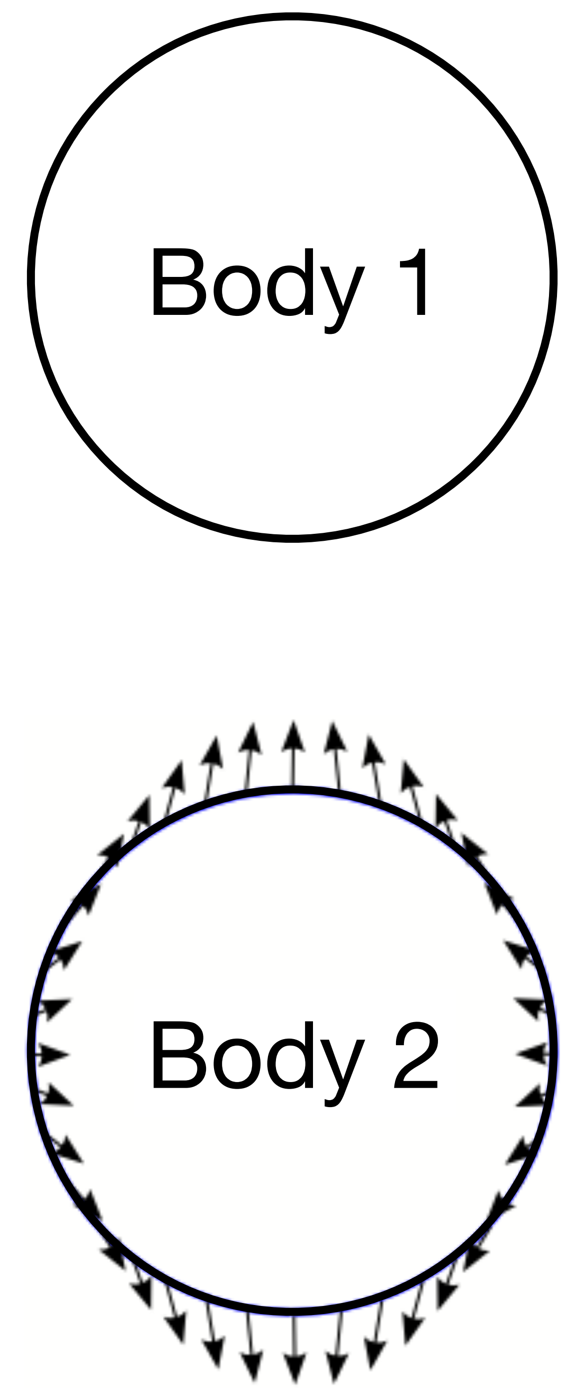
NS-NS Binaries

- To find the CBC waveform, each body is approximated as a point particle
- NS-NS binaries will depart from the point particle approximation during the late inspiral phase
- ***Tidal forces*** will deform NSs depending on their internal structure



Physical Description of Tidal Forces

- The gravitational field of Body 1 falls off as $1/r^2$
- Therefore, the gravitational field across Body 2 is not constant
- The ***tidal force*** is a result of the relative difference in strength of the gravitational field across Body 2
- The tidal ***love number*** λ parameterizes how much a body will deform due to tidal forces



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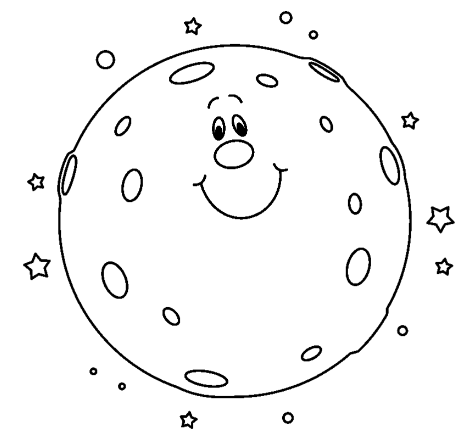

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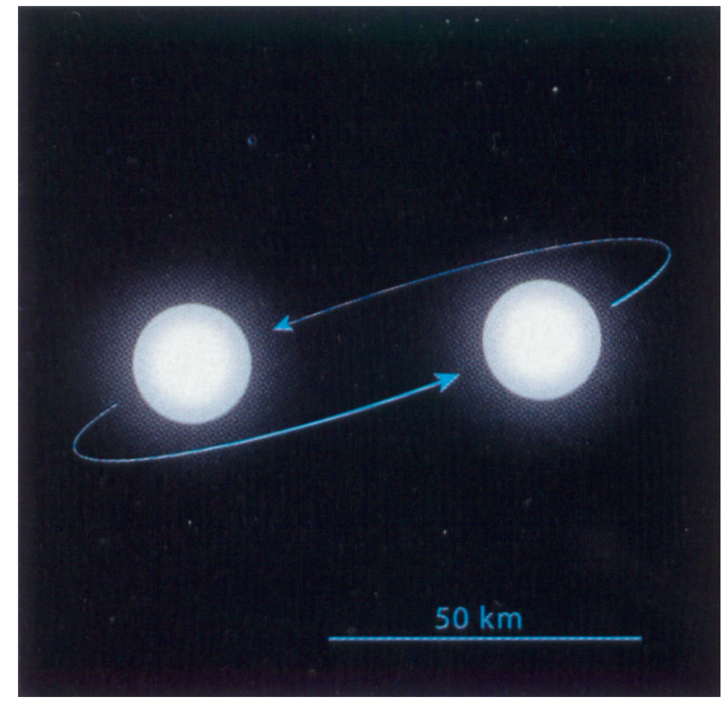

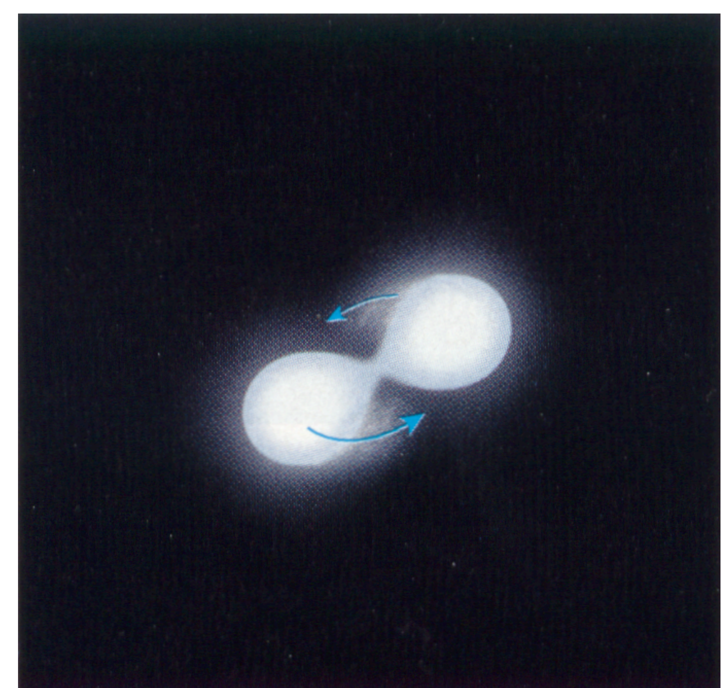

Motivation: Constraining NS Equation of State

- Tidal corrections depend only on the love number

- Accurately determining the love number can constrain the NS equation of state (EOS)

- The NS EOS is useful for ***fundamental physics*** and ***astrophysics***

    - Fundamental physics: Better understand NS matter, which will expand our understanding of phase diagrams at high energies

    - Astrophysics: Gravitational detection can independently provide a distance-redshift relationship

NS-NS Binary Waveform

- The point particle approximation to the NS-NS binary waveform:

$$\tilde{h}(f) = \mathcal{A} f^{-7/6} \exp\left[i\psi(f)\right]$$

where the phase is

$$\psi(f) = \psi_{3.5} + \mathcal{O}(v^8)$$

where $v = (\pi M f)^{1/3}$

NS-NS Binary Waveform + Tidal Corrections

- The point particle approximation to the NS-NS binary waveform:

$$\tilde{h}(f) = \mathcal{A} f^{-7/6} \exp\left[i\psi(f)\right]$$

where the phase is

of order v^{10} beyond leading order

$$\psi(f) = \psi_{3.5} + \delta\psi_{\rm tidal} + \mathcal{O}(v^8)$$

where $v = (\pi M f)^{1/3}$ and

$$\delta\psi_{\rm tidal} = -\frac{117}{8}\frac{\tilde{\lambda} v^5}{\eta M^5}$$

where $\tilde{\lambda}$ is a linear combination of λ_1 and λ_2

Notable Work with Tides

- ***Early inspiral*** (low frequencies) with analytic waveforms
  - Flanagan and Hinderer (2008): Find that aLIGO will be able to constrain λ even though tidal influences are minimal at low frequencies.
  - Hinderer *et al.* (2010): Find that the measurement error in λ steeply increases with the total mass of the binary. They conclude that aLIGO will only be able to probe stiff EOSs while the proposed Einstein Telescope would likely see a clean tidal signature.
- ***Late inspiral*** (high frequencies) with numerically simulated waveforms
  - Read *et al.* (2009): Find that greater measurement accuracy can be achieved at high frequencies and produce quantitative estimates of NS EOS measurability with aLIGO.

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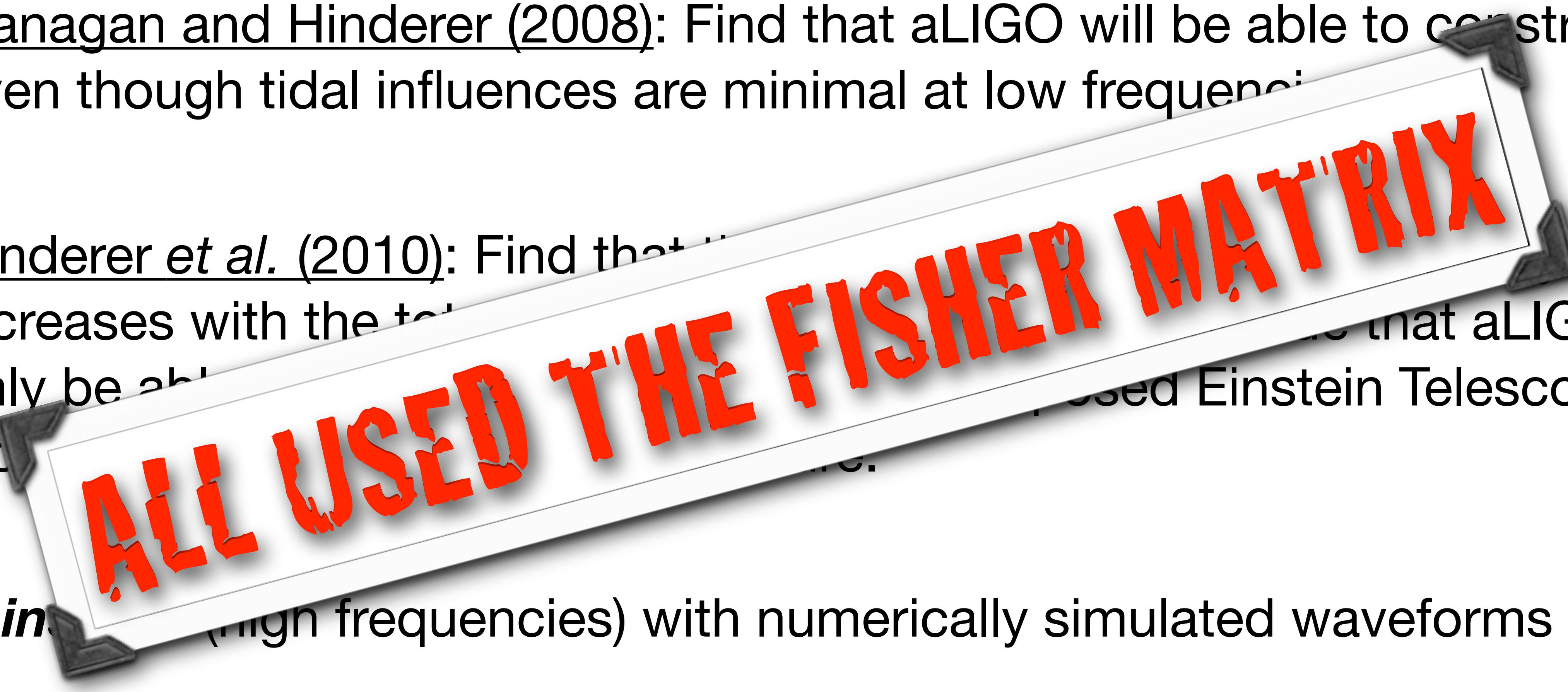

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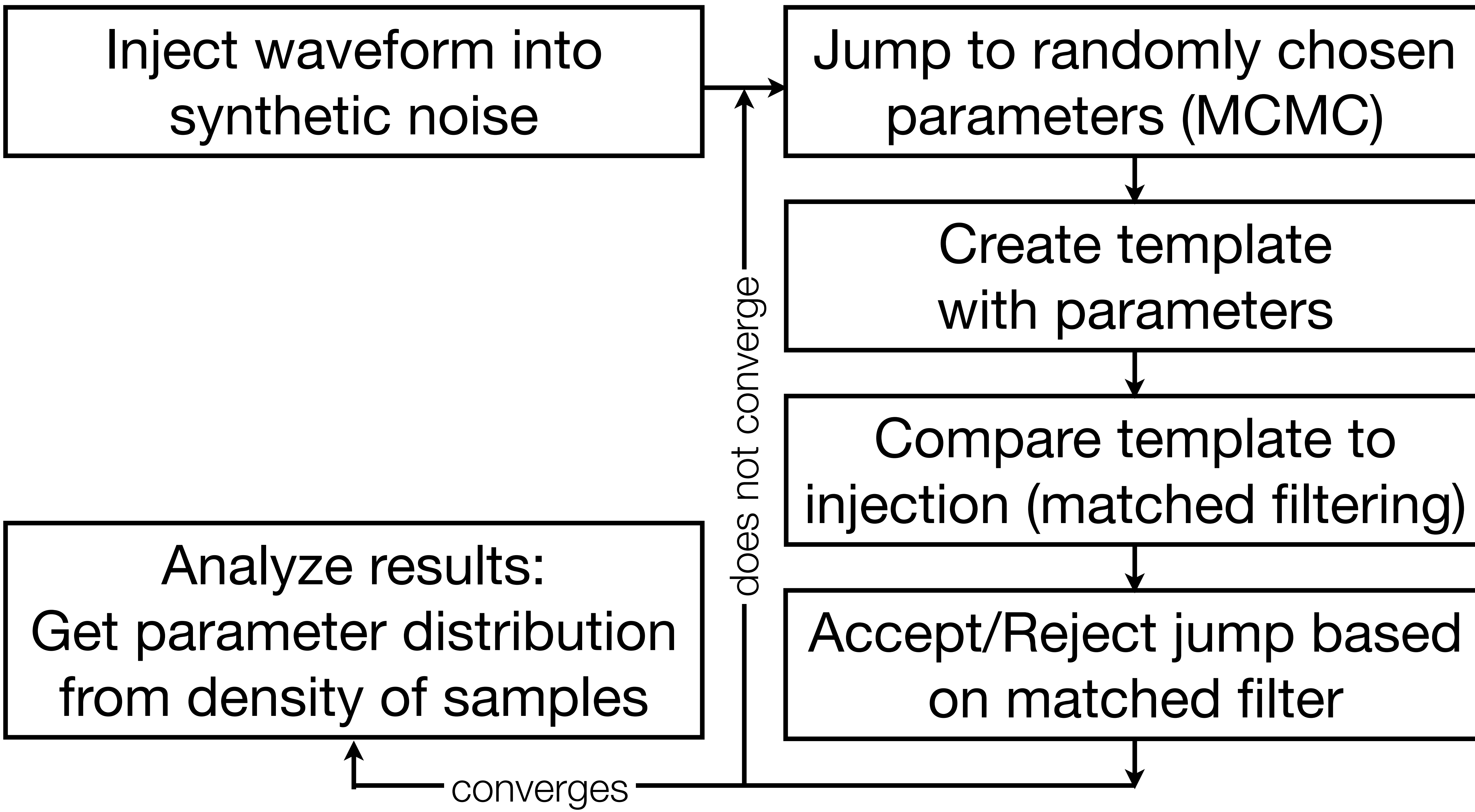
Proposed Contribution

- Full ***Markov Chain Monte Carlo*** (MCMC) runs instead of just Fisher matrix
  - Explore all signal parameters
  - Avoid Fisher matrix assumptions (particularly high signal-to-noise-ratio)
  - Work toward actual parameter estimation method for aLIGO
- Add tidal corrections to several more LAL waveform families
  - Use multiple waveform families to study ***systematic biases*** in our parameter estimation method

Parameter Estimation



Summary

- Gravitational wave detectors such as aLIGO may be able to significantly constrain the NS EOS through the addition of tidal corrections to our current waveforms

- Past efforts to determine the measurement error of the tidal love number with gravitational wave detectors have used the Fisher matrix

- We will run full MCMC runs which will produce much more realistic results

- We will use different post-Newtonian waveforms with tidal corrections to better understand systematic biases