# Using numerical relativity waveforms in gravitational wave searches

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# Introduction

- Two classes of searches relevant for BBH systems
  - Un-modeled bursts
  - Matched filter searches (inspiral/ringdown)
- We want to improve these pipelines using information from numerical relativity
  - How do existing pipelines perform with NR waveforms?
  - Can we use information from NR to make our vetoes and coincidence tests better? This is important for improving false alarm rates and thus the sensitivity of our searches.
  - Immediate need for ongoing S5 searches. Probably not feasible to do full NR based merger search for S5, but we need to know how well current searches perform.
  - How important are spins and higher modes for detection?
  - Should we use matched filtering to search for the merger?
- Many of these issues can be addressed before we have solved the PN-NR matching and template bank problems

# Introduction

- To start addressing these questions, we need to be able to inject NR waveforms
- Injection studies (hardware and software) are a crucial ingredient in all GW searches
- Provides end-to-end test and comparisons of pipelines
- Powerful way to study complicated data analysis questions which are hard to understand analytically – non-stationarities and non-gaussianities, efficiencies, upper limits, parameter space structure etc.
- A large fraction of the time for carrying out a search is spent in injection studies

# Exchanging data with NR groups

- To start injection studies, we need to exchange numerical waveforms with NR groups
- Data analysis people involved directly: D. Brown, S. Fairhurst, R. Kopparapu, B. Krishnan, R.A. Mercer, L. Santamaria, J.T. Whelan
- Document specifying data formats for the exchange: `arXiv:0709.0093 [gr-qc]`
- Is this a sensible data format? Comments and suggestions are welcome

# The data format

The time and the waveforms scale with $M$

$$h_{ij} = A_{ij}\frac{M}{r} + \mathcal{O}\left(r^{-2}\right) , \qquad h_{ij} = h_{+}\left(\mathbf{e}_{+}\right)_{ij} + h_{\times}\left(\mathbf{e}_{\times}\right)_{ij}$$

We work with the mode decomposition in spin weighted spherical harmonics:

$$h_{+} - ih_{\times} = \frac{M}{r}\sum_{\ell=2}^{\infty}\sum_{m=-\ell}^{\ell} H_{\ell m}(t)\ {}^{-2}Y_{\ell m}(\iota,\phi) .$$

$$rh_{+}^{(\ell m)}(t) - irh_{\times}^{(\ell m)}(t) \equiv MH_{\ell m}(t) .$$

Provide $rh_{+}^{(\ell m)}(t)$, $rh_{\times}^{(\ell m)}(t)$ and a metadata file for each NR simulation

# What we intend to do to the data

- ASCII files are converted to “frame files” (one for each simulation) and metadata is contained in the file itself
- Intention is to distribute the frame files within the LSC by usual mechanism used for LIGO data itself $\Longrightarrow$ every LSC member can access the waveforms
- Use these frame files to create a population of NR signals with different masses, sky positions, orientations at different times and inject into pipelines
- Immediate aim is to set up the infrastructure to do these injections
- We want to get started with this as soon as possible – first using simulated data and later with real data

# A toy example with the inspiral searches

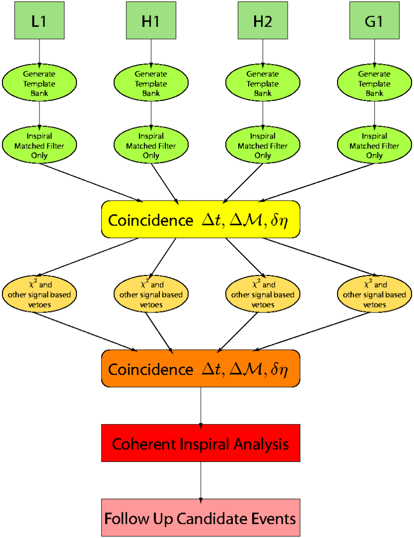
- Inject a polulation of 10 hybrid waveforms with
- $3M_\odot < m_1, m_2 < 35M_\odot$
- $6M_\odot < m_1 + m_2 < 40M_\odot$
- $1Mpc < d < 100Mpc$
- Systems assumed to be optimally oriented

Try to recover them with

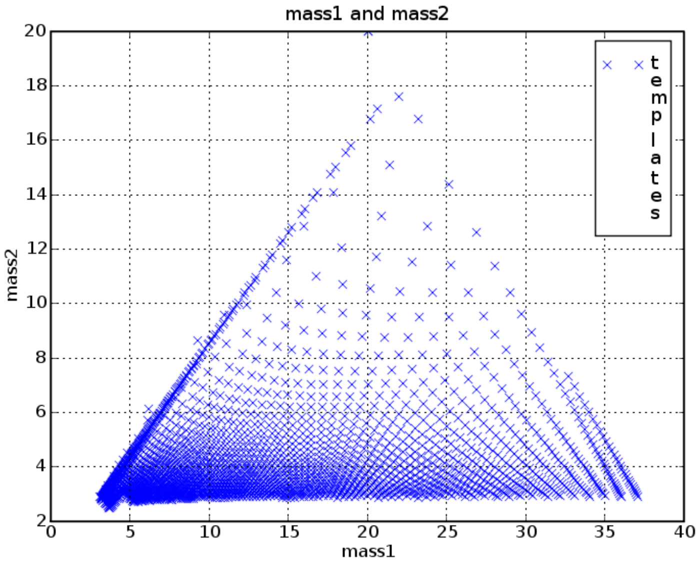
- TaylorT1 2-PN template bank
- 2100 templates, minimal match = 0.97
- $3M_\odot < m_1 < 35M_\odot$
- $m_1 + m_2 < 40M_\odot$

Want to look at parameter estimation accuracy

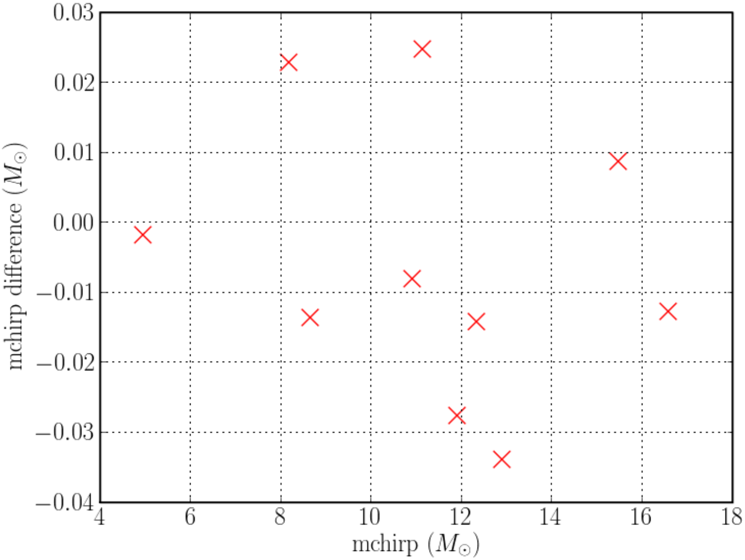
# The inspiral pipeline



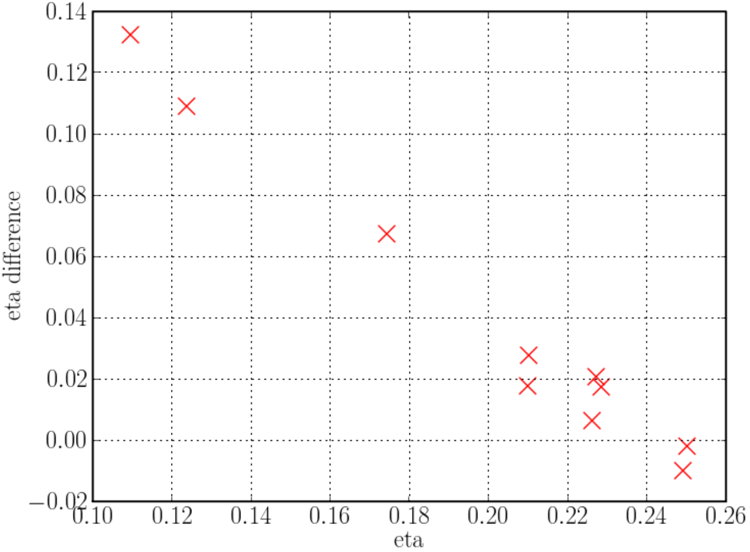
# The template bank used



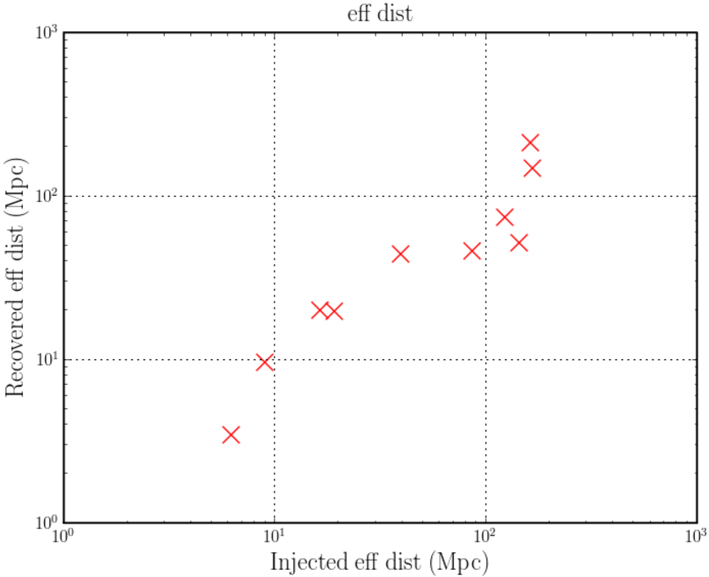
# Chirp-mass estimation



# Symmetric mass ratio estimation



# The effective distance



# Conclusions

- Even before solving the template construction problem, input from numrel can help improve our searches
- The ability to inject numrel waveforms is very important, and we have made progress in this direction
- We would like to start this data exchange as soon as possible
- Next....
    - NR injections in a burst pipeline – Adam Mercer
    - Status of ringdown searches – Jolien Creighton