An inspiral-merger-ringdown waveform model for compact binaries on eccentric orbits
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Outline

- Motivation
- Waveform model construction
- Applications
- Future work

Motivation

- Gravitational wave astrophysics is already revolutionizing our understanding of the Universe [GW Highlights Sessions on Tuesday]

- Near future: accurate census of the mass and angular momentum distribution of compact sources; constraints on their channels of formation and evolution, and the environments where they reside

Extend the science reach of gravitational wave astrophysics

- Eccentric compact binaries may form in dense stellar environments and retain eccentricity during their lifetime [*Fabian (1975), Pooley (2003), O'Leary (2009), East & Pretorius (2013), Lee et al (2010), D. Tsang (2013), L. Wen (2003), D. Tsang (2013)*]

- Detecting these sources will provide unique insights about compact object populations in globular clusters and galactic nuclei [*Maccarone et al (2007), Irwin et al (2010), Strader et al (2012), Antonini (2014), Hopman et al (2006), Rodriguez et al (2015)*]

Motivation

- The detection of GW150914 made evident that we needed inspiral-merger-ringdown (IMR) waveform models to constrain the residual eccentricity of gravitational waves [**Ian Hinder (Monday), Adam Lewis (Thursday)**, *Arun et al 2009, Yunes et al (2009), Hinder et al 2010, Huerta and Brown (2012), Huerta et al (2014)*]

- We have developed a model that is suitable for this analysis, under the assumption that the binary components are non-spinning (Huerta, Kumar, et al. In review) [LIGO-P1600186]

- The corresponding manuscript was submitted for LIGO's internal review on June 08. It has been reviewed and accepted.

Structure of the *ax* model

PN-based inspiral

All known eccentricity corrections up to 3PN order. Fluxes include instantaneous, tails, tails-of-tails contributions, and a contribution due to non-linear memory [Arun et al (2009)]

Caveat: lacks accuracy for systems with asymmetric mass-ratios

Improved inspiral: Self force + Black Hole Perturbation Theory

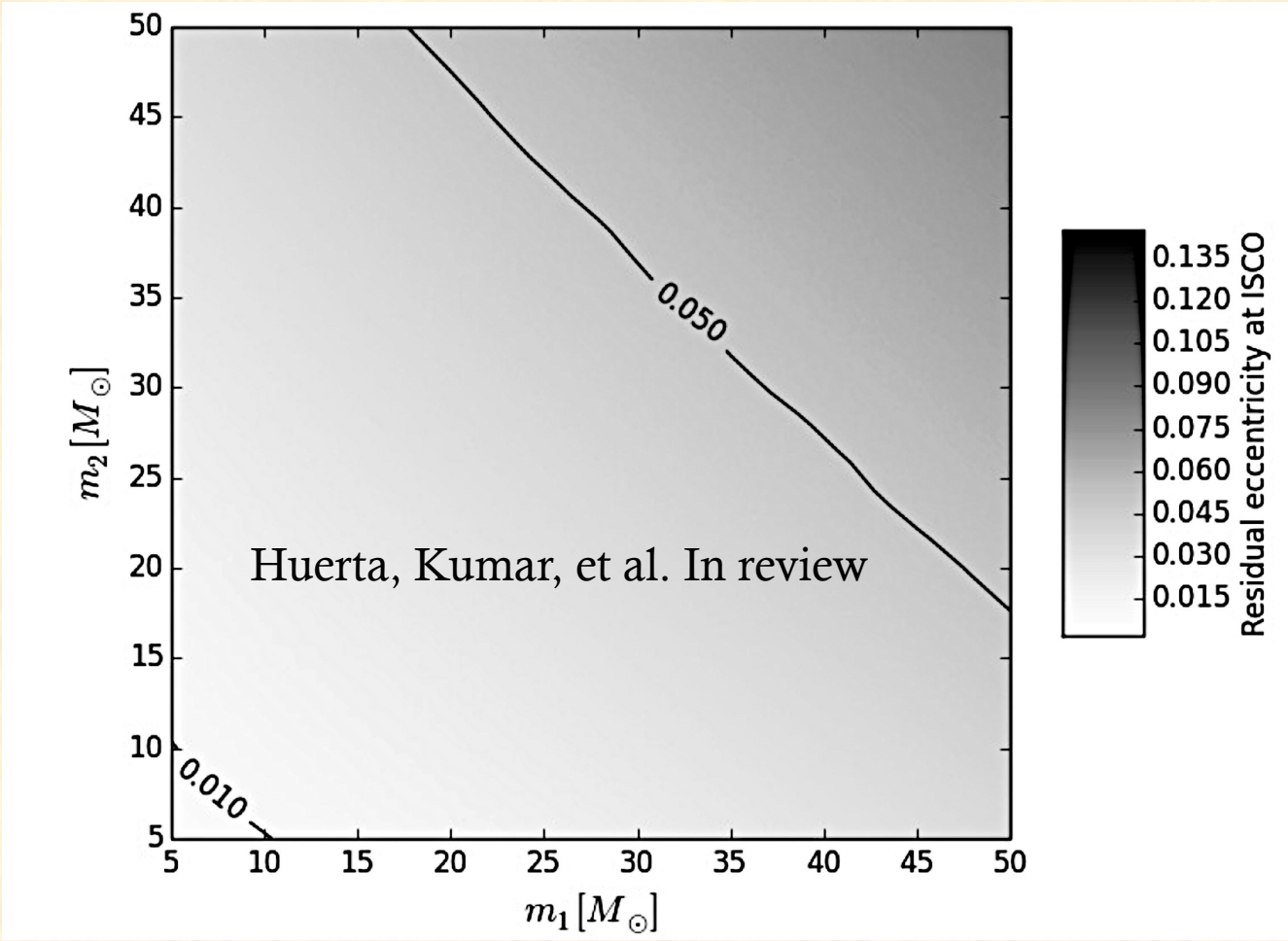
Flux of energy and binding energy up to 6PN order including linear in mass-ratio corrections [Fujita (2012), Barusse et al (2012), Damour et al (2013)]

Benefit: improves accuracy for asymmetric quasi-circular mass-ratio binaries

Eccentricity decay

BBH population with an initial eccentricity e=0.3 at a GW frequency of 15Hz.

Moderately eccentric binaries circularize prior to the merger event



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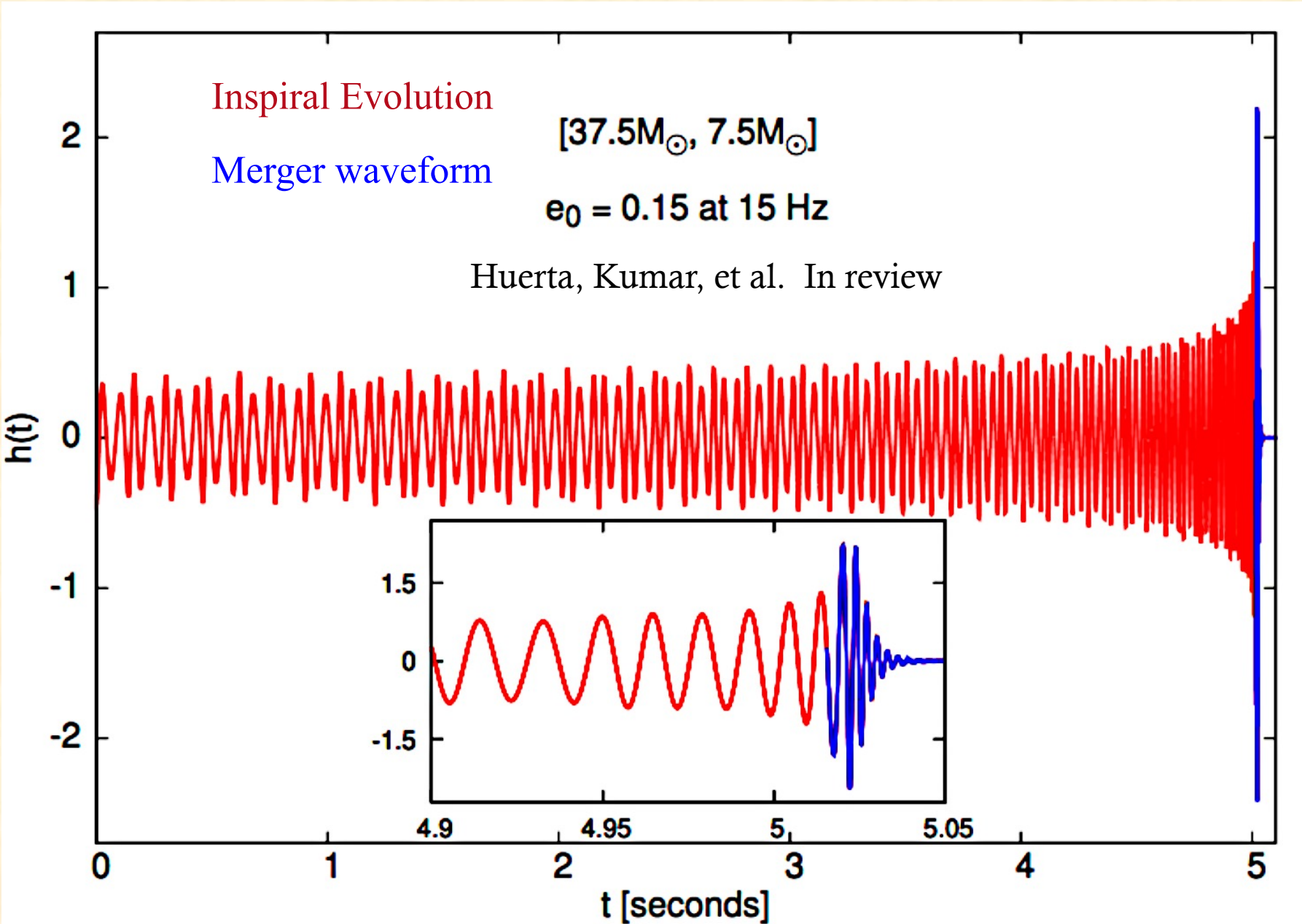
Quasi-circular merger waveform

Implicit Rotating Source (IRS) formalism calibrated with numerical relativity simulations up to mass-ratio 10 [Baker et al (2008), Kelly et al (2010)]

Caveat: very accurate only in the vicinity of the light-ring

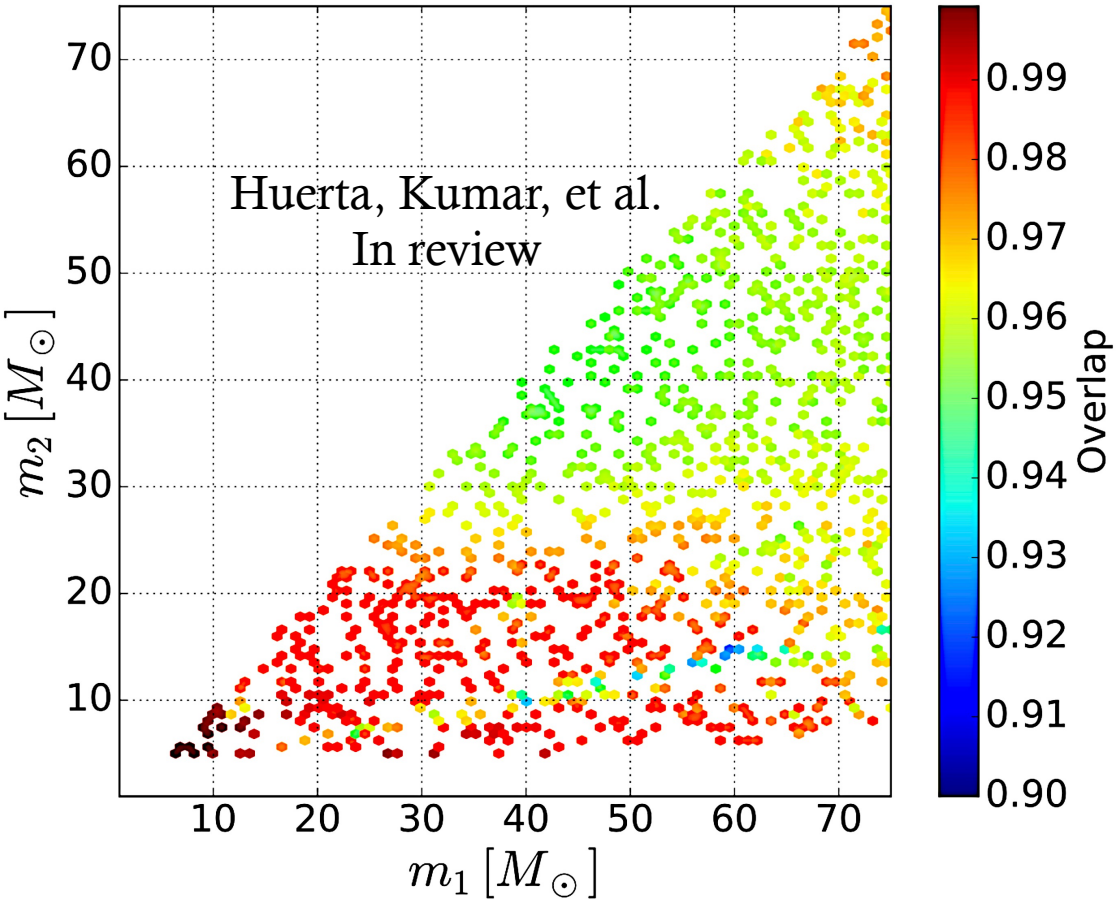
Complete waveform



Comparison to state-of-the-art quasi-circular waveforms in the zero eccentricity limit

PSD: mid-aLIGO
Initial filtering frequency: 25Hz

IMR eccentric model agrees well with the effective-one-body model (EOBNRv2) over a wide range of the BBH parameter space accessible to aLIGO



Comparison to EOBNRv2 in the zero eccentricity limit

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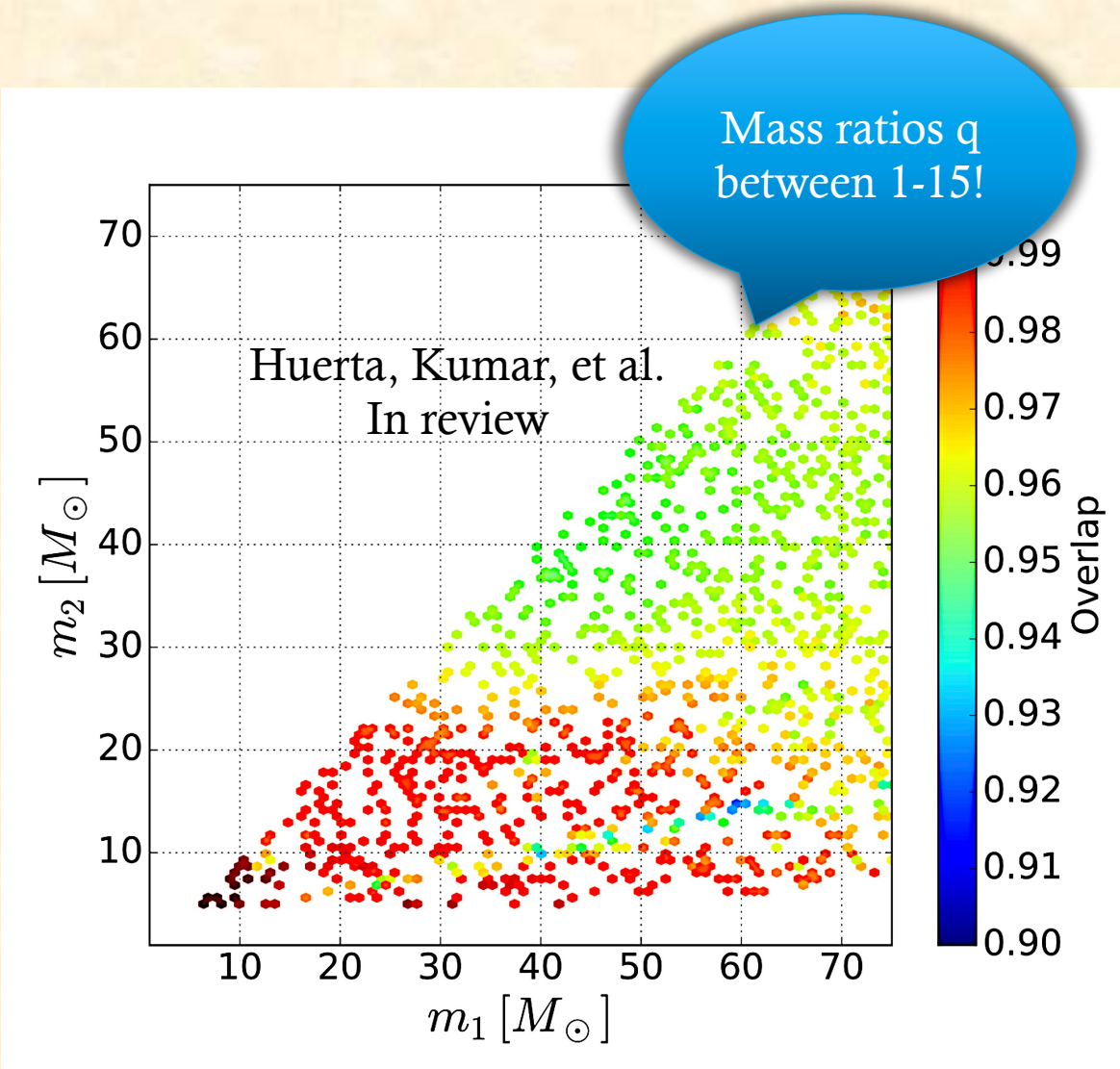

Comparison to EOBNRv2 in the zero eccentricity limit

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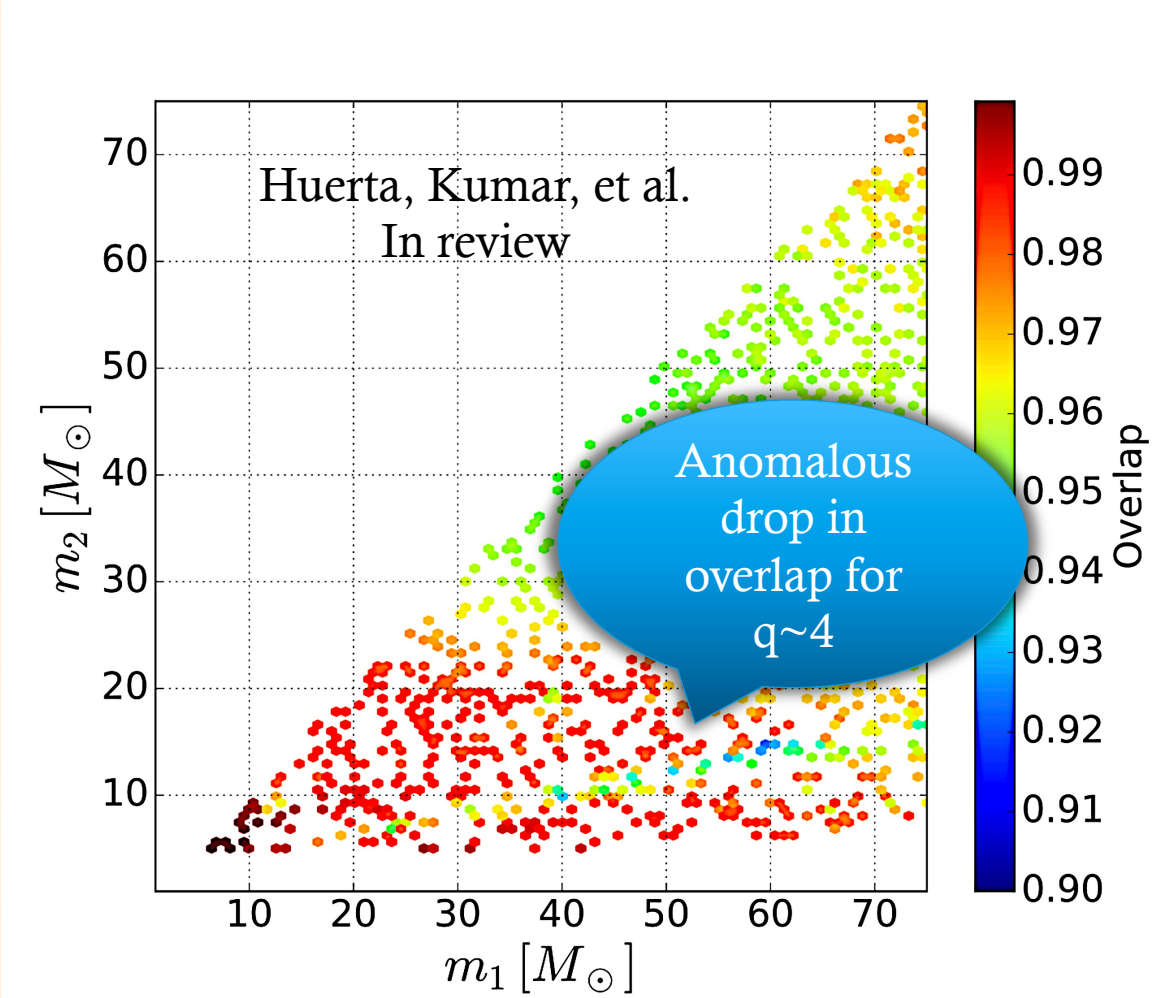
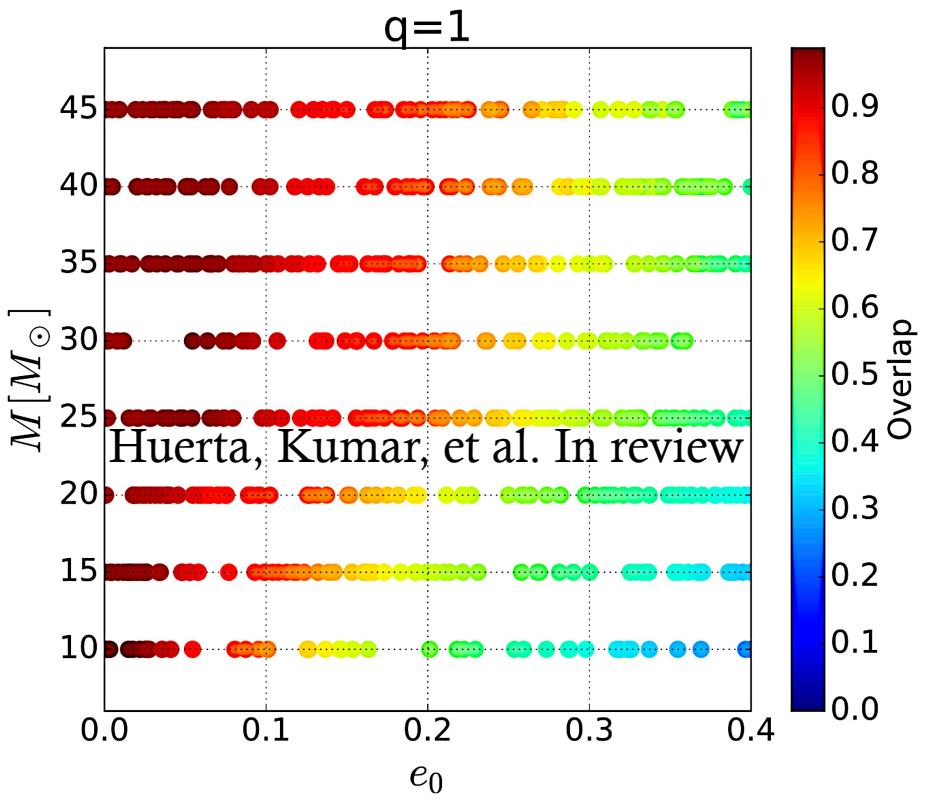
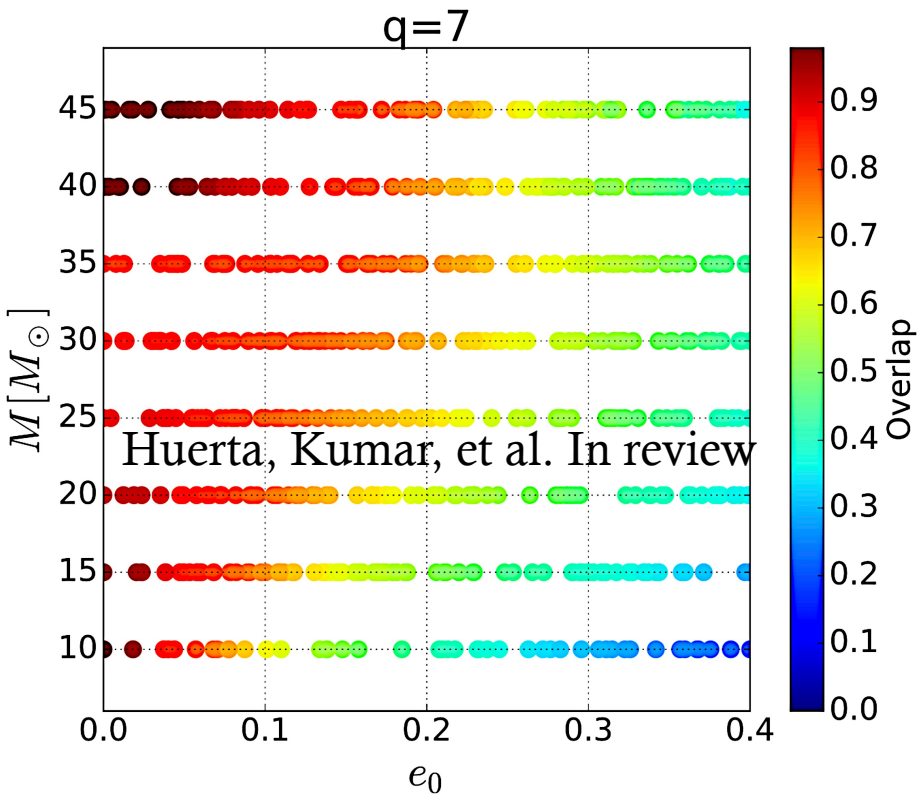
Improved version of the merger waveform using a larger set of NR simulations



Applications

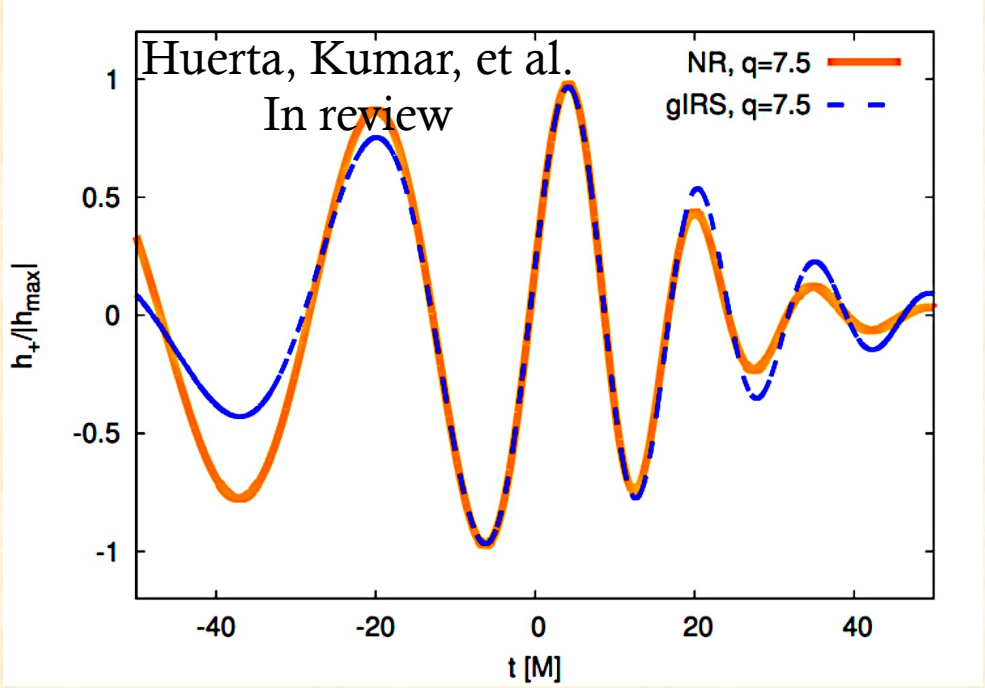
PSD: Zero Detuned High Power
Initial filtering frequency: 15Hz
Eccentricity of x-axis defined at a GW frequency of 15Hz





Improving the merger model

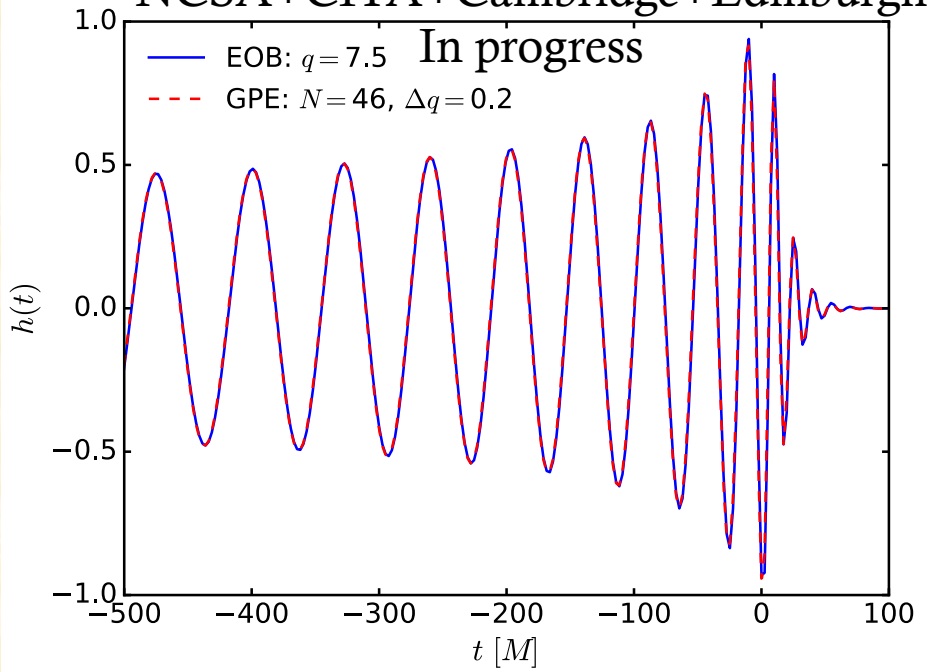
NCSA: Miguel Holgado and Erik Wessel
Cambridge: Alvin Chua and Chris Moore
CITA: Harald Pfeiffer and Prayush Kumar
Edinburgh: Jon Gair



gIRS works very well ***in the vicinity of the light-ring***

Our new approach works very well ***several cycles before merger!***

NCSA+CITA+Cambridge+Edinburgh
In progress



Future work

- With Ian Hinder: quantify the accuracy of our IMR models using numerical relativity simulations for astrophysically motivated sources

- We will use our models to quantify how accurately we can constrain the residual eccentricity of new detections with aLIGO

- We are developing new tools to detect and characterize eccentric sources. Network of collaborators: NCSA (USA), CITA (Canada), Cambridge (UK), Edinburgh (UK), AEI (Germany) and ICTS (India)

Conclusions

- We have combined PN, self-force, black hole perturbation theory and numerical relativity to develop the first IMR model that can describe eccentric binaries with asymmetric mass-ratios

- We have shown that the model agrees well with EOBNRv2 in the zero eccentricity limit

- An improved version of the model is currently under construction to address two key issues:
  - Increase overlap with EOBNRv2 in the quasi-circular limit
  - Include spin of the binary components

Inspiral dominated systems

Power Spectral Density: Zero Detuned High Power
Initial frequency for filtering: 15Hz
Eccentricity on the x-axis defined at a GW frequency of 15Hz

TaylorT4 3.5PN vs *ax* model