Precessing binary black holes simulations

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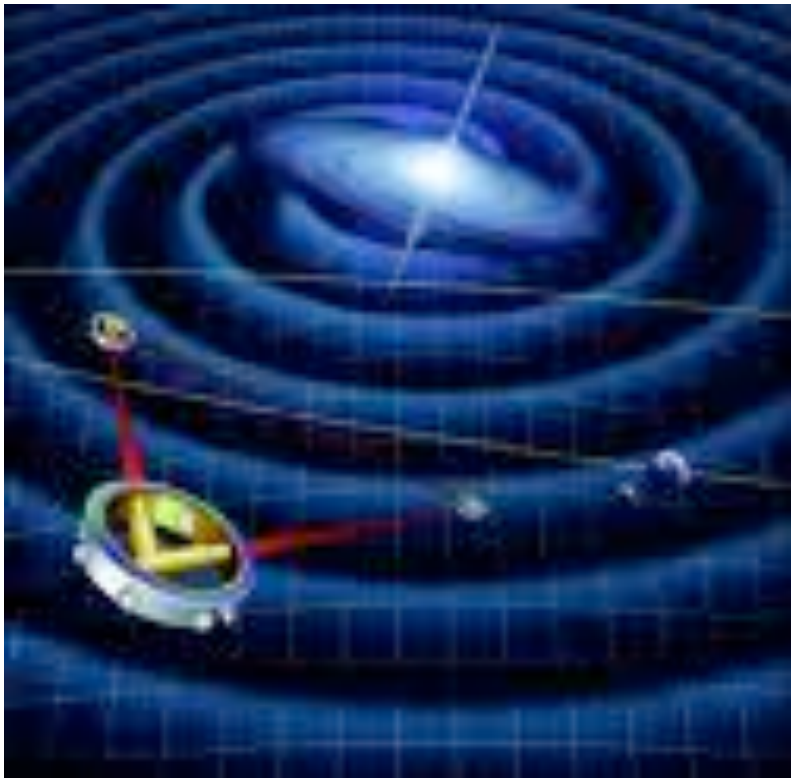
Outline

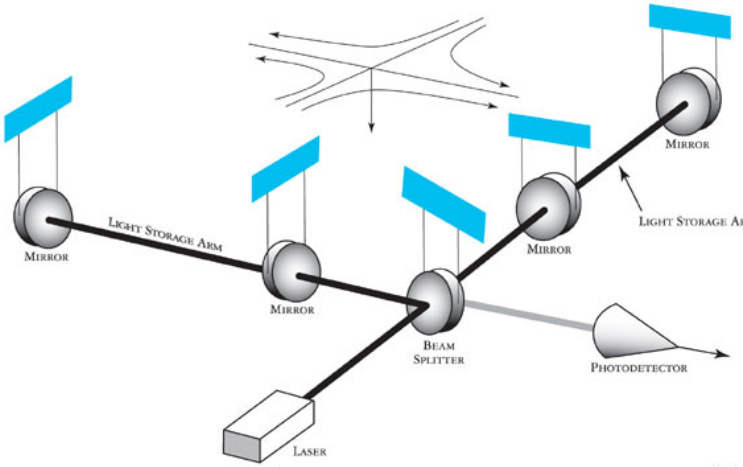
- Motivation:
  - Gravitational waves
  - LIGO
- Binary black holes simulations:
  - Quasi-circular Initial data
  - Numerical waveforms
- Analytical models:
  - Post-Newtonian approximations
  - Spin effects
  - Eccentricity and periastron advance

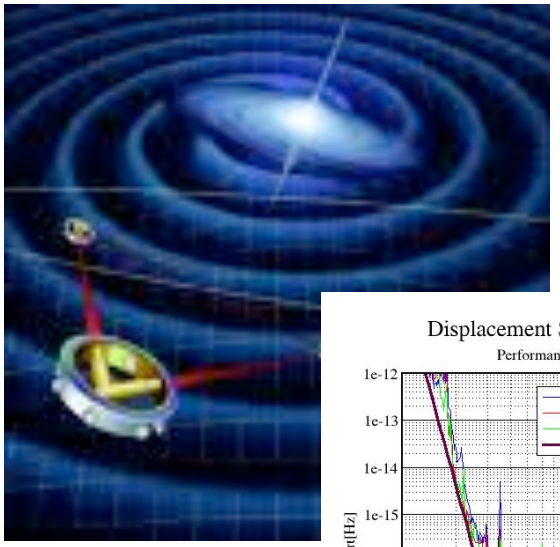
Gravitational wave detectors

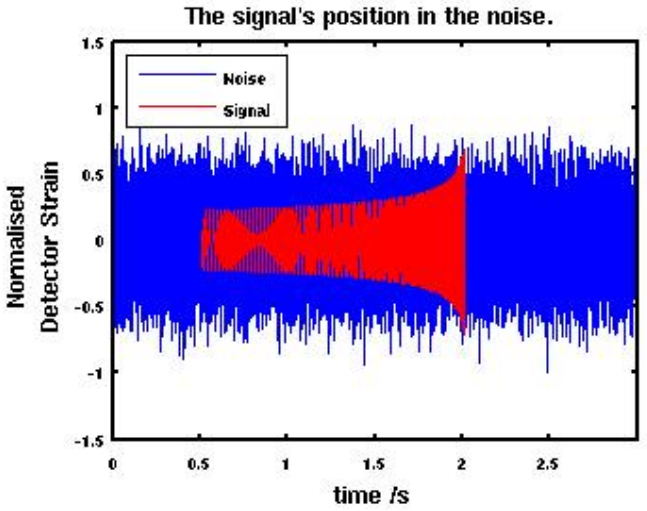


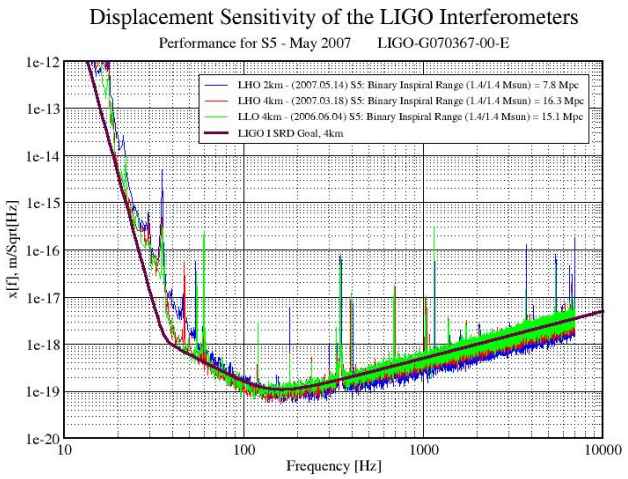
- Possible sources:
  - Binary black holes
  - Black hole-Neutron star

Gravitational wave detectors









es

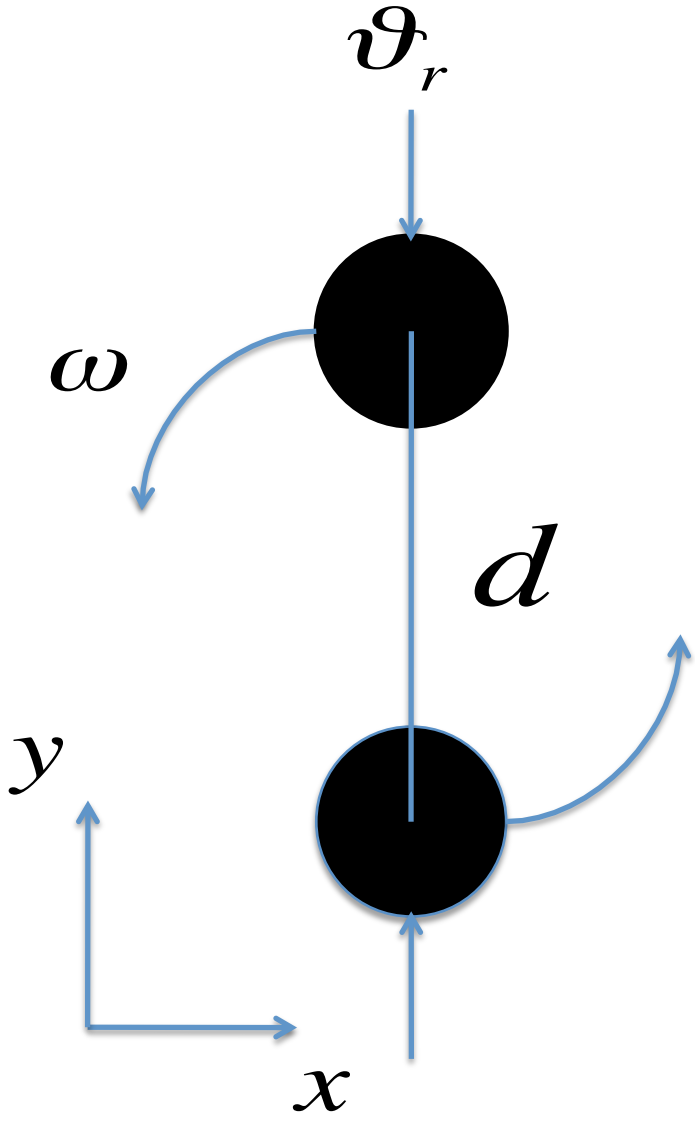
on star

$$\frac{\delta L}{L} \sim h \sim 10^{-21}$$

Binary black holes

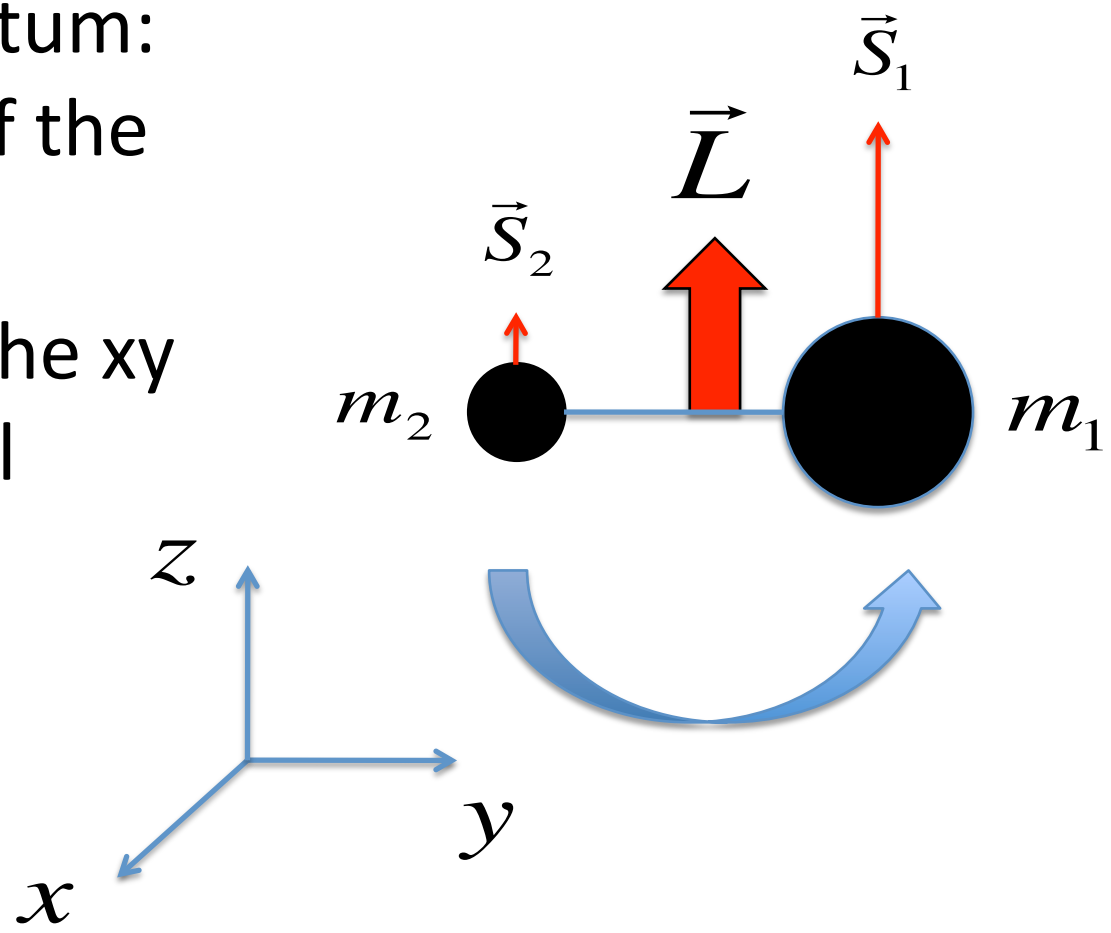
- Initial data parameters:
  - Orbital frequency
  - Separation
  - Radial velocity
- Initial PN guess: generate eccentric orbits
- Costly iterative procedure

Isolated binaries are quasi-circular. How to reduce eccentricity?



Spinning binaries

- Spins parallel to angular momentum: no precession of the spins
- Trajectory is in the xy plane: no orbital precession

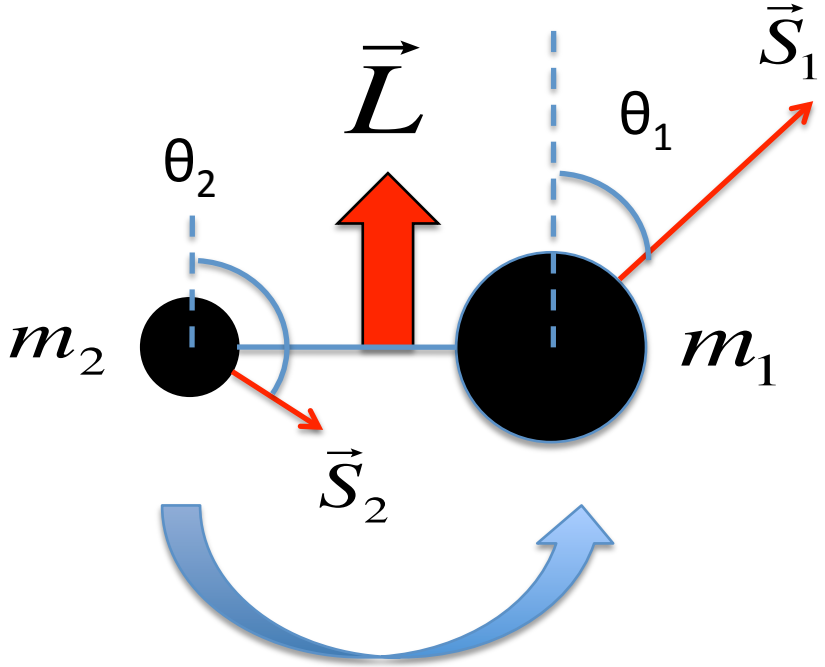


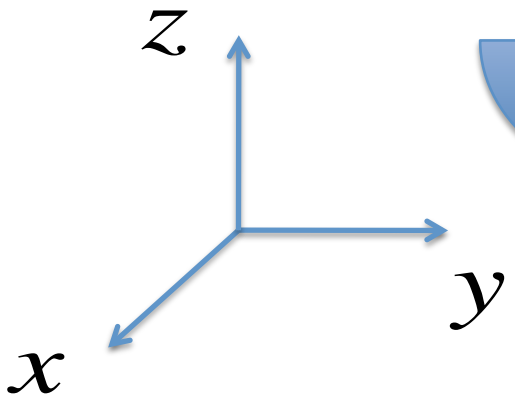
Precessing binaries

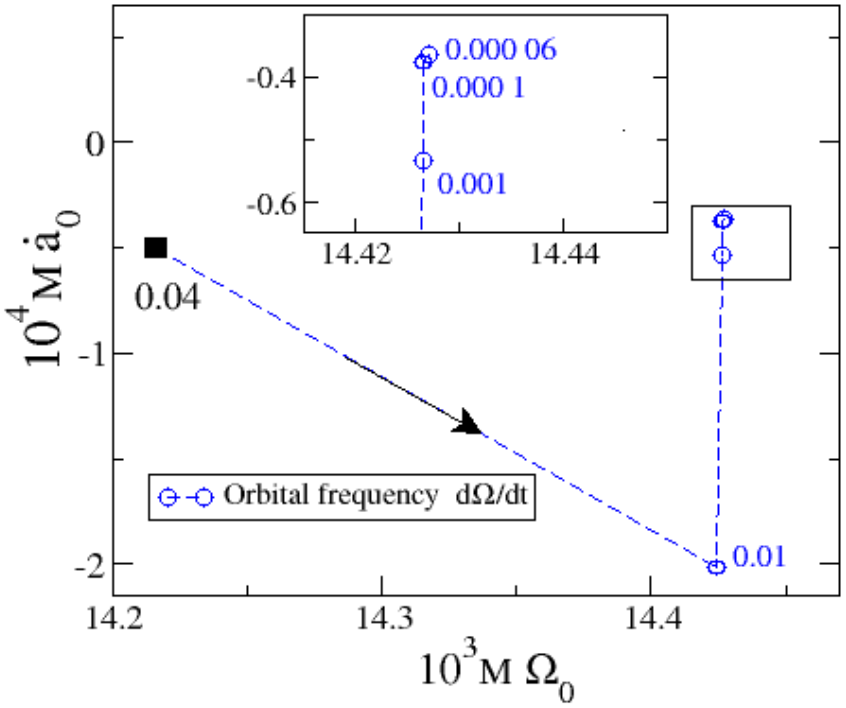
- Spins precession
- Orbital plane precession
- Spin-Orbit and Spin-Spin effects:

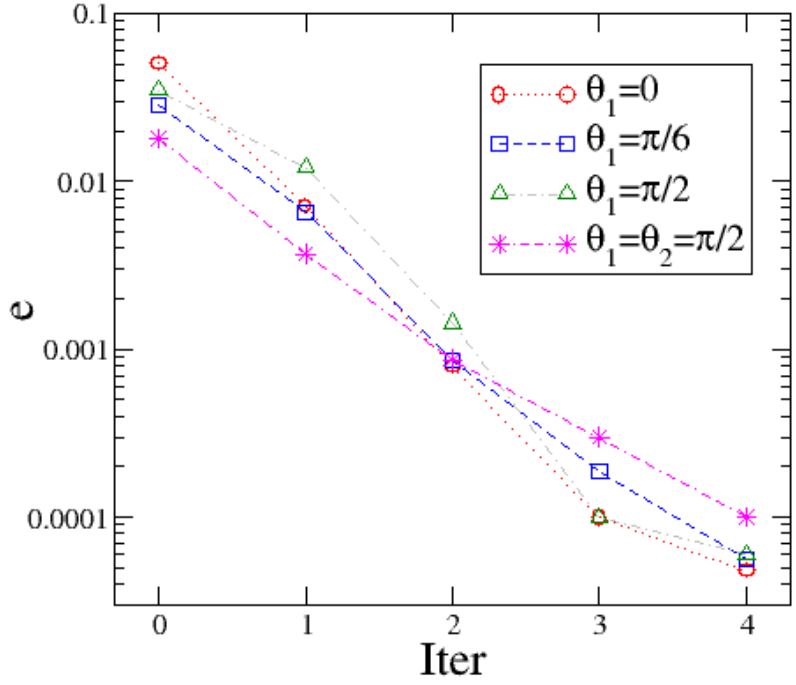
$$\ddot{r} = ... + ..(S_{eff} \cdot \hat{n})/r^5 + ...(S_{eff} \times \hat{n})/r^3$$
$$+ ...(S_0 \cdot \hat{n})/r^4 + ...$$

- Similarly for Ω

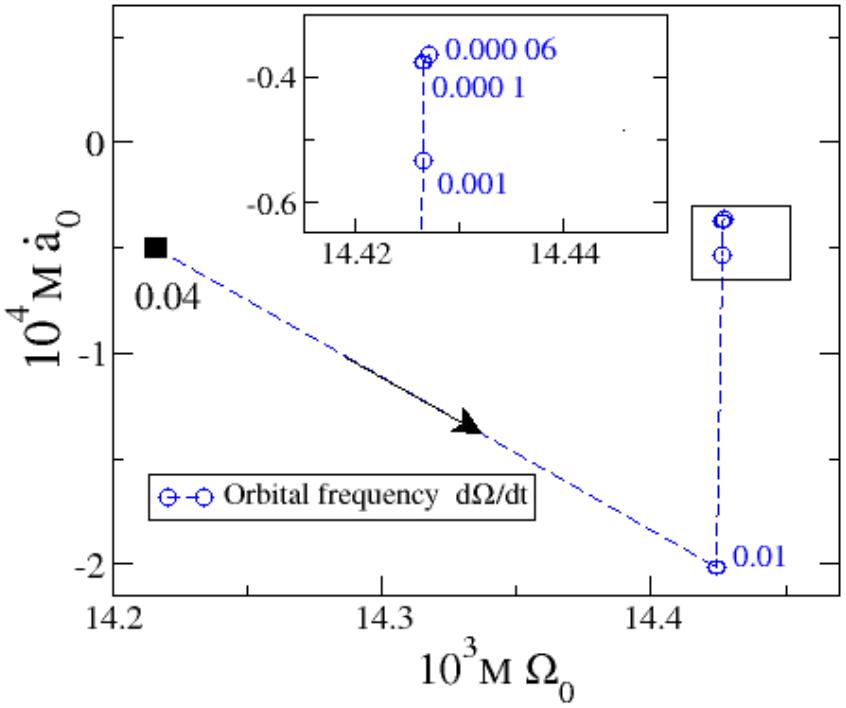








Use orbital frequency Ω to reduce eccentricity



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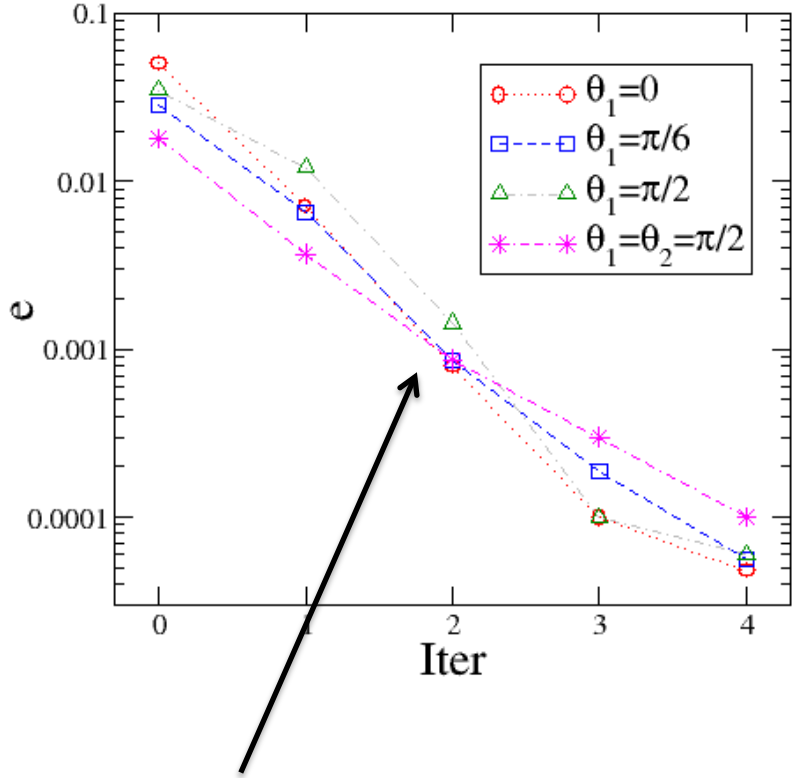
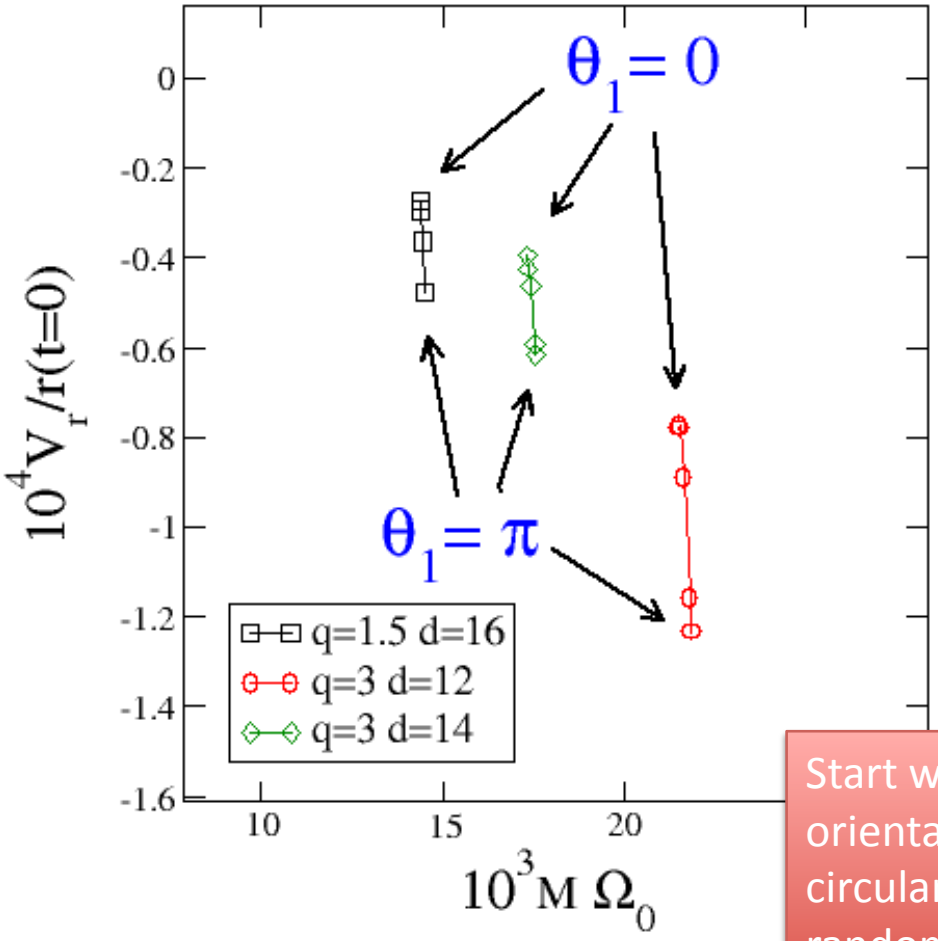


We want to start here



Start with 90 deg. spin orientations then quasi-circularize binaries with random spins orientations

15 binary configurations with spin 0.5, e~0.00005

Fitting formulas to reduce the number of ecc-removal iterations

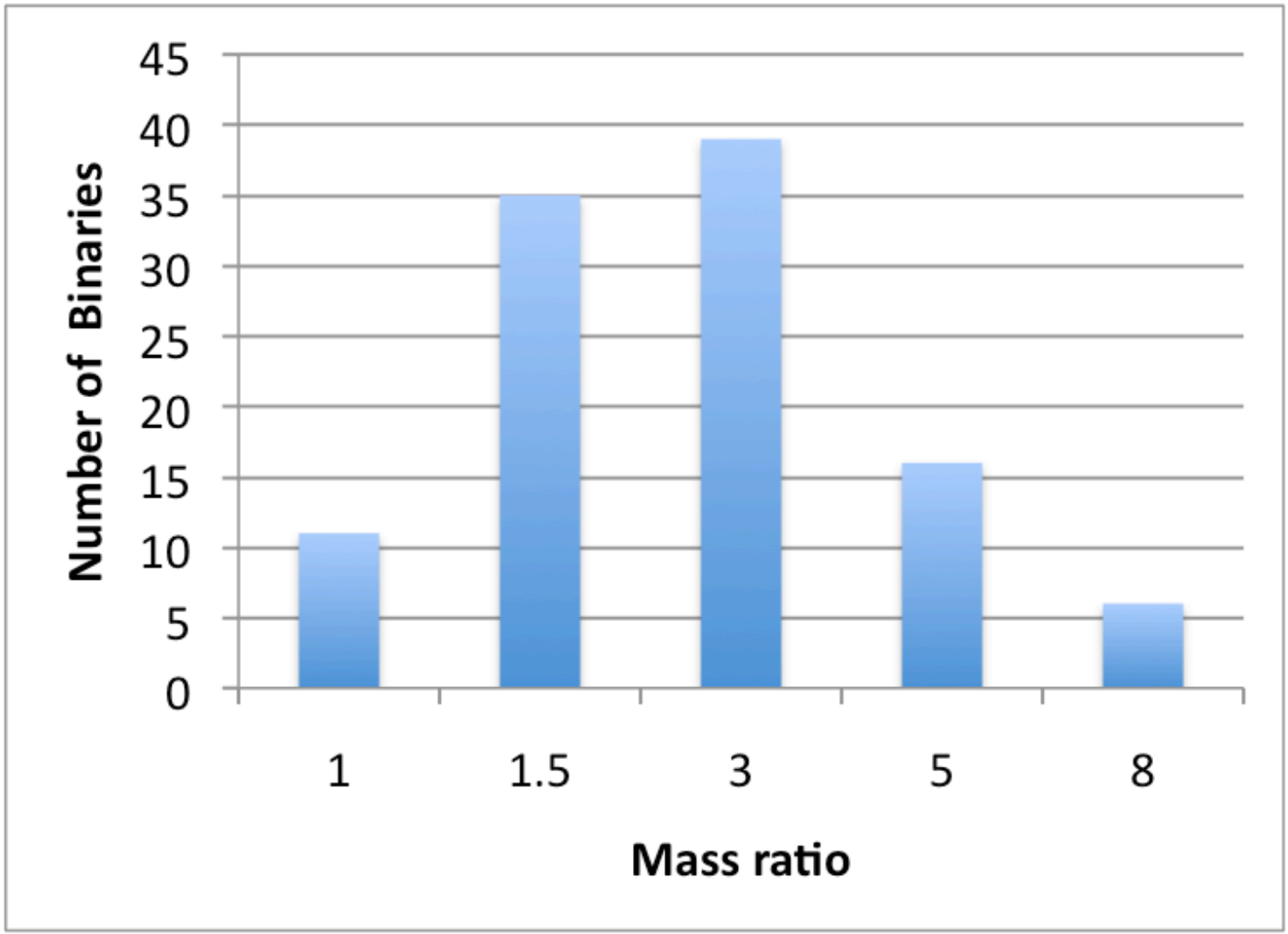
Binaries distribution

- ~90 spinning binaries:
  - One/two spinning holes with $\chi_{1,2}$ =0.5
  - Most precessing
  - 70 quasi-circular
- ~10 nonspinning binaries
- Evolved on SciNet

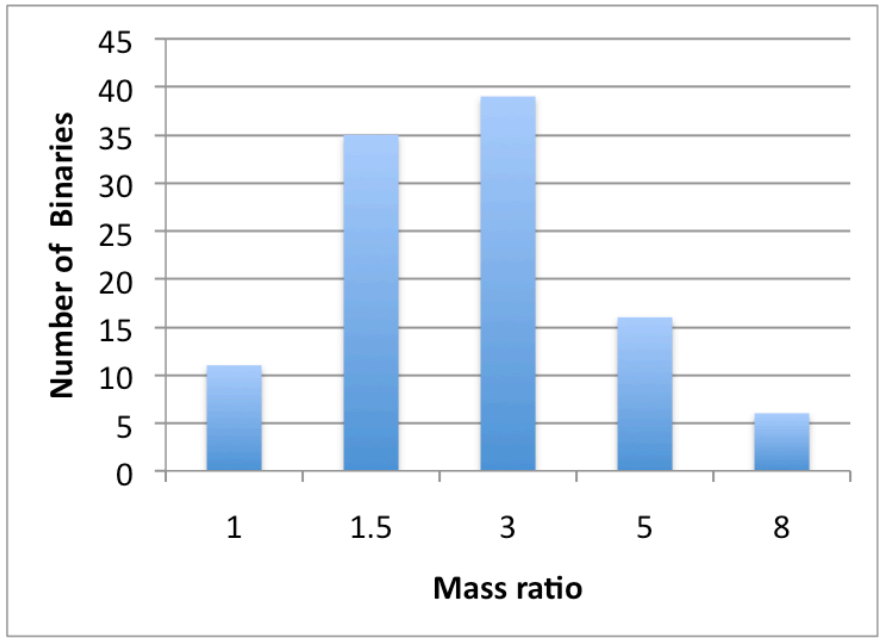
$$m_1/m_2 = \begin{pmatrix} 1 \\ 1.5 \\ 3 \\ 5 \\ 8 \end{pmatrix} \quad \theta_{1,2} = \begin{pmatrix} 0° \\ 30° \\ 90° \\ 150° \\ 180° \end{pmatrix} \quad \Phi_{1,2} = \begin{pmatrix} 0° \\ 90° \\ 180° \\ 270° \end{pmatrix}$$

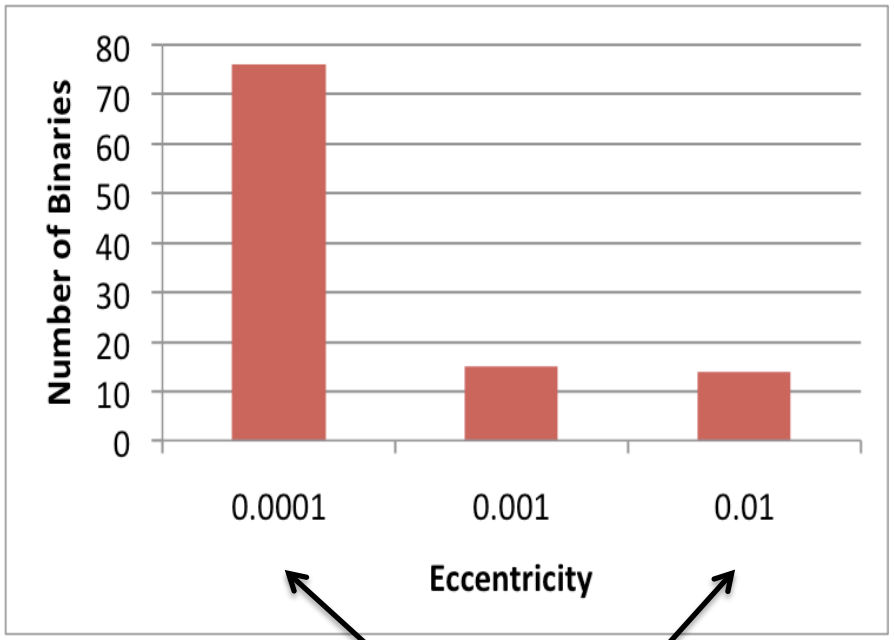
+ some binaries with random spin directions

Binaries distribution



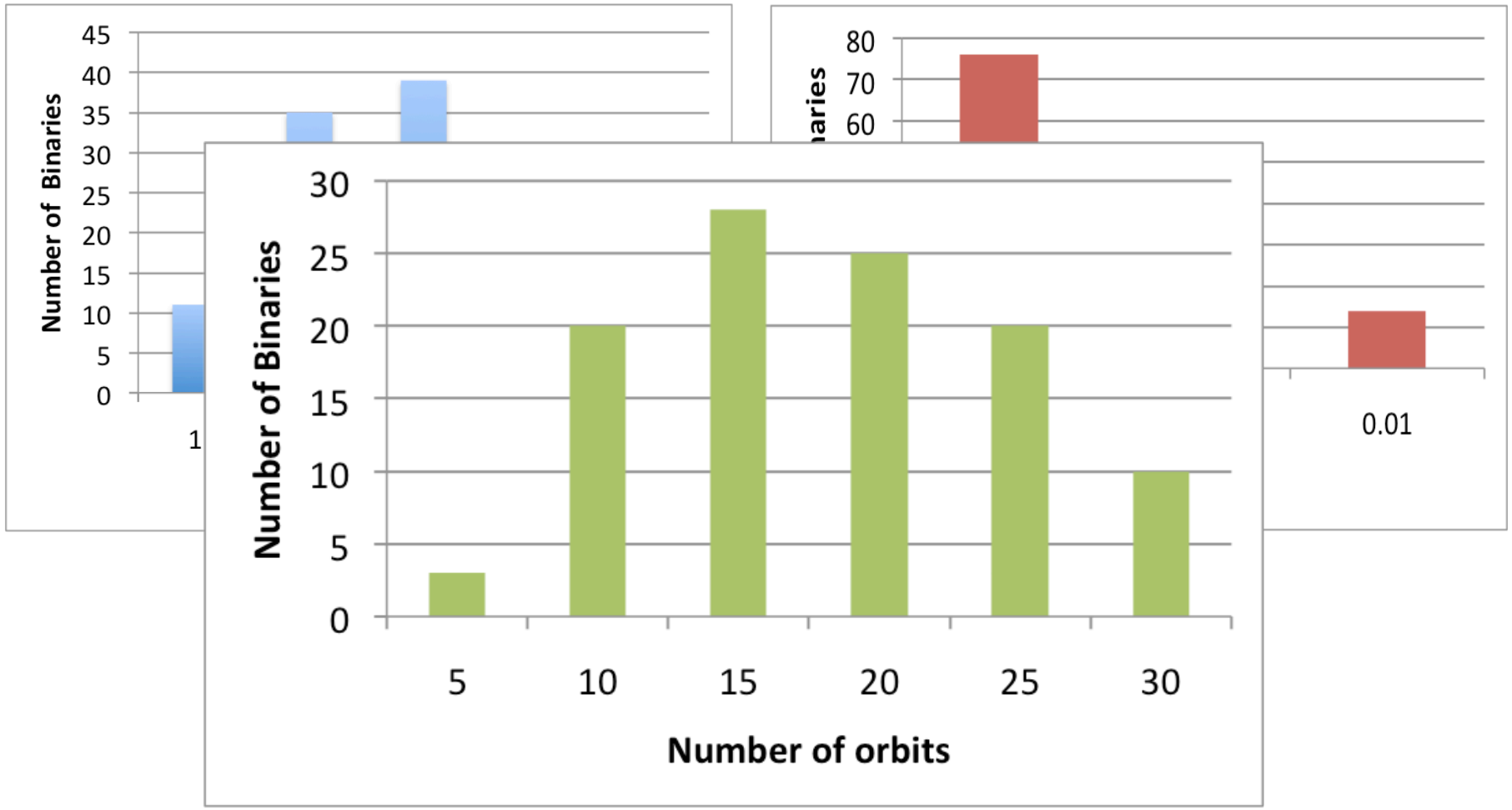
Binaries distribution

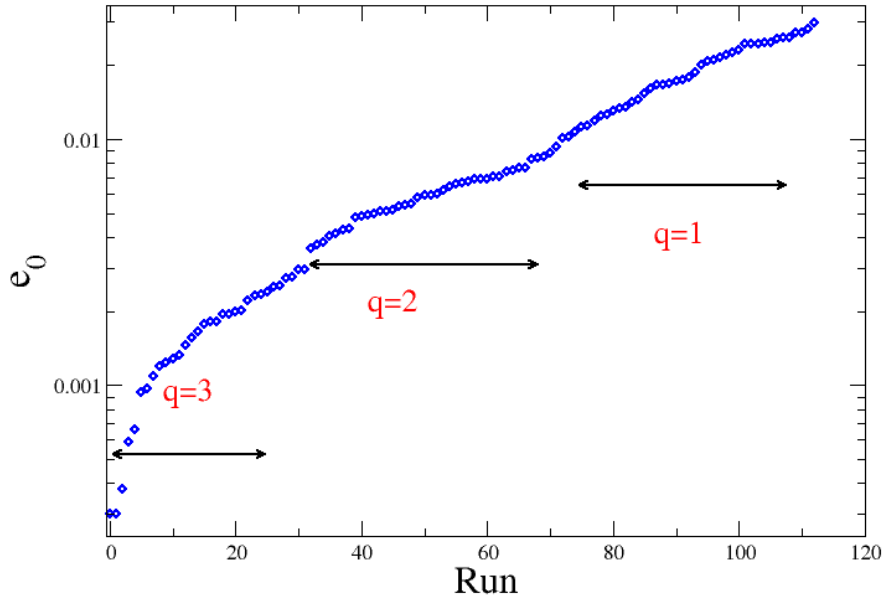


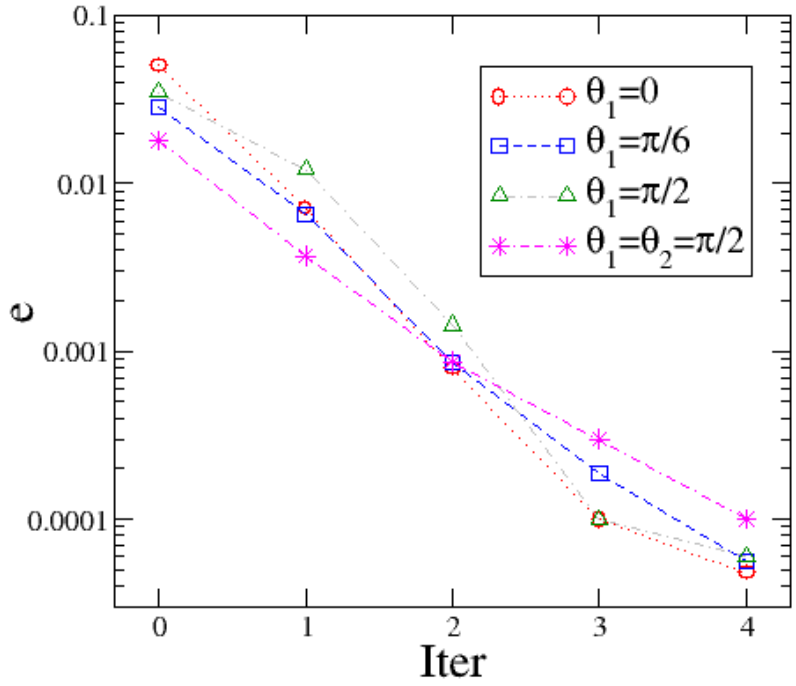


Compare waveforms..

Binaries distribution





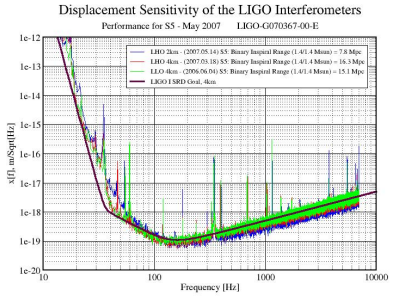


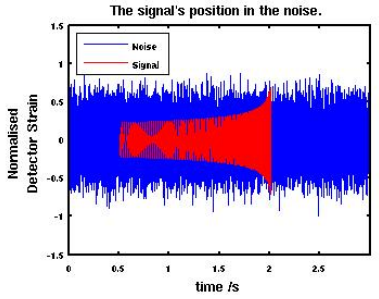
Reduce initial eccentricity

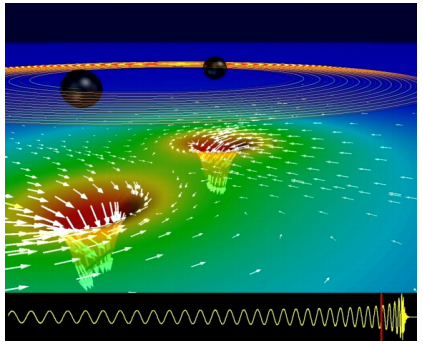
Needs more improvements for Mass ratio q=1

Can we model GW accurately?

- Detected signal depends on 15 parameters
- Numerical simulations depend on 7 parameters
- Many waveforms are needed
- Computationally costly

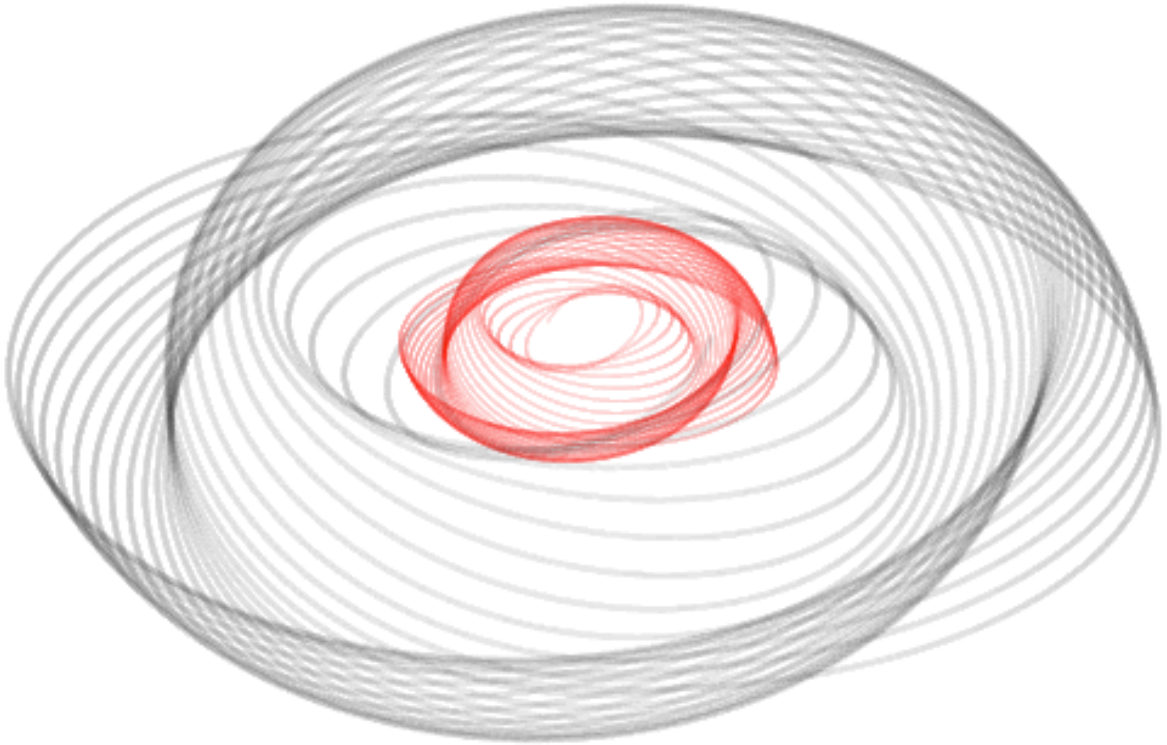


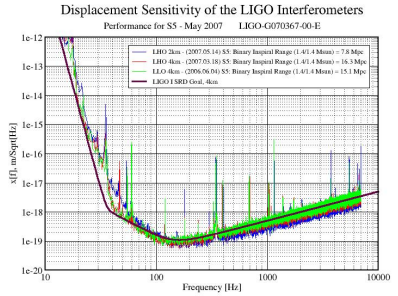


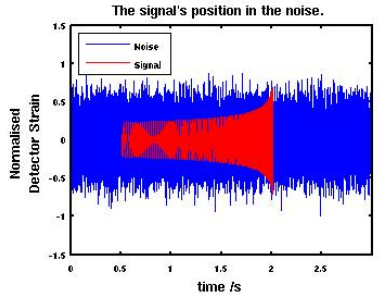


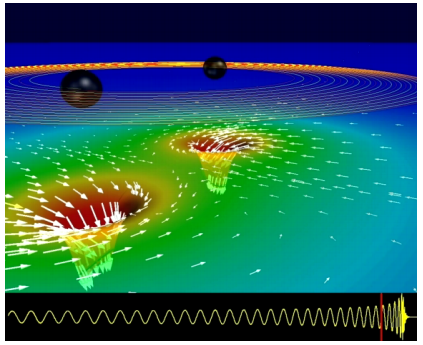
1 month for a 15-orbit run on 32 cores

Can we model GW accurately?



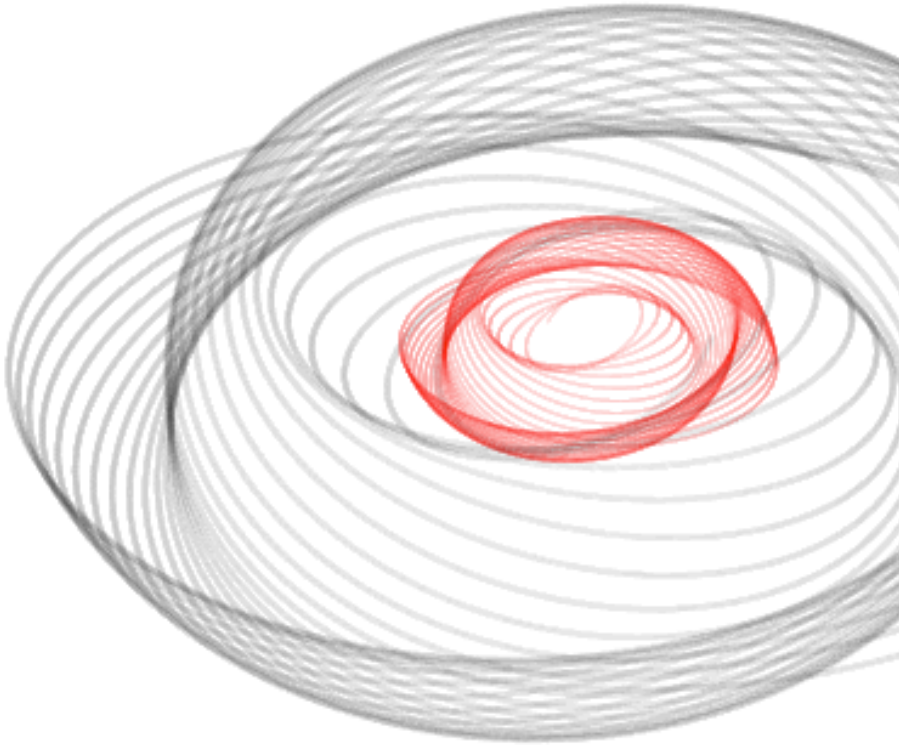


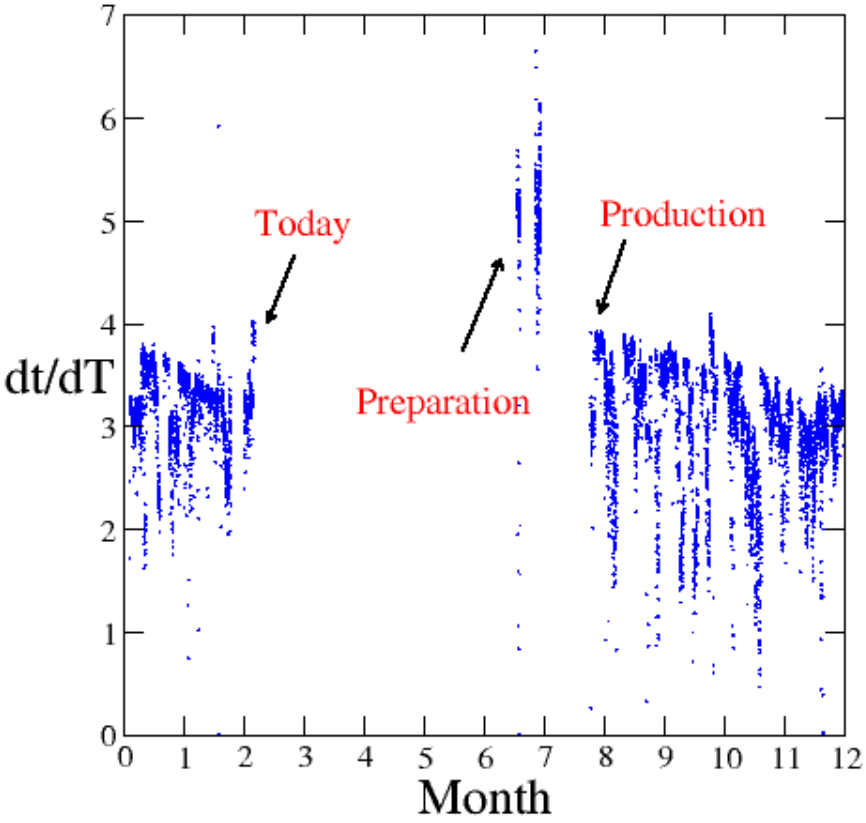




8 month for a 30-orbit run on 64 cores

Can we model GW accurately?





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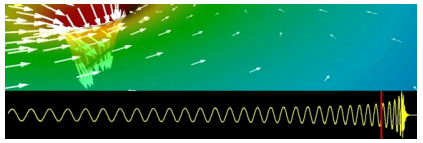
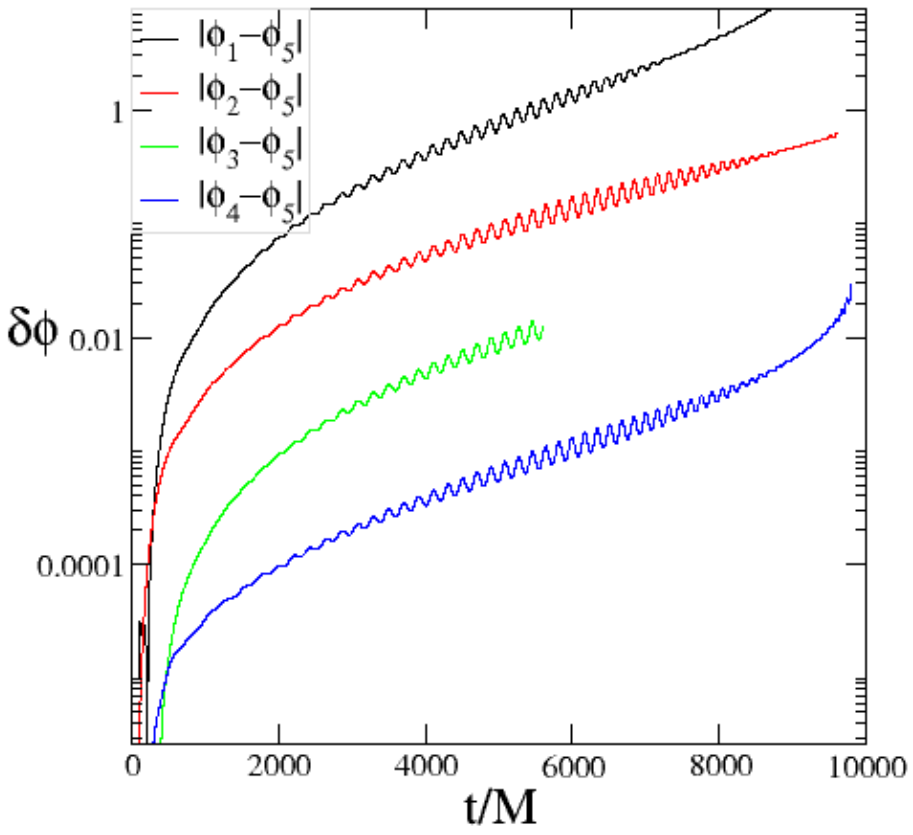
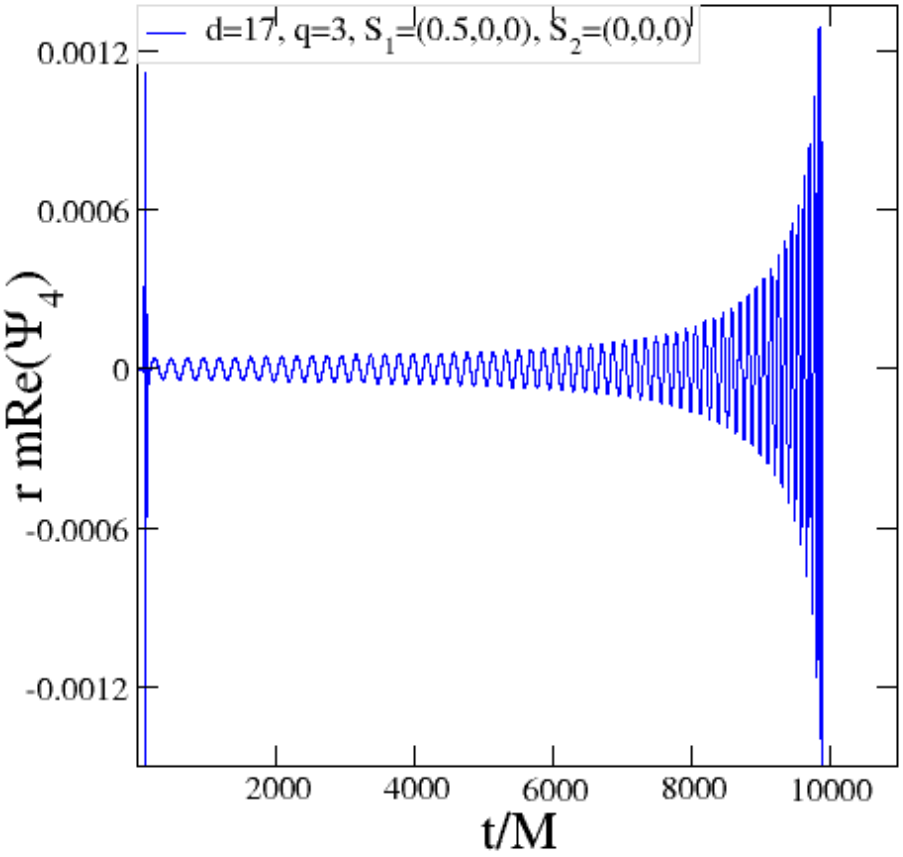
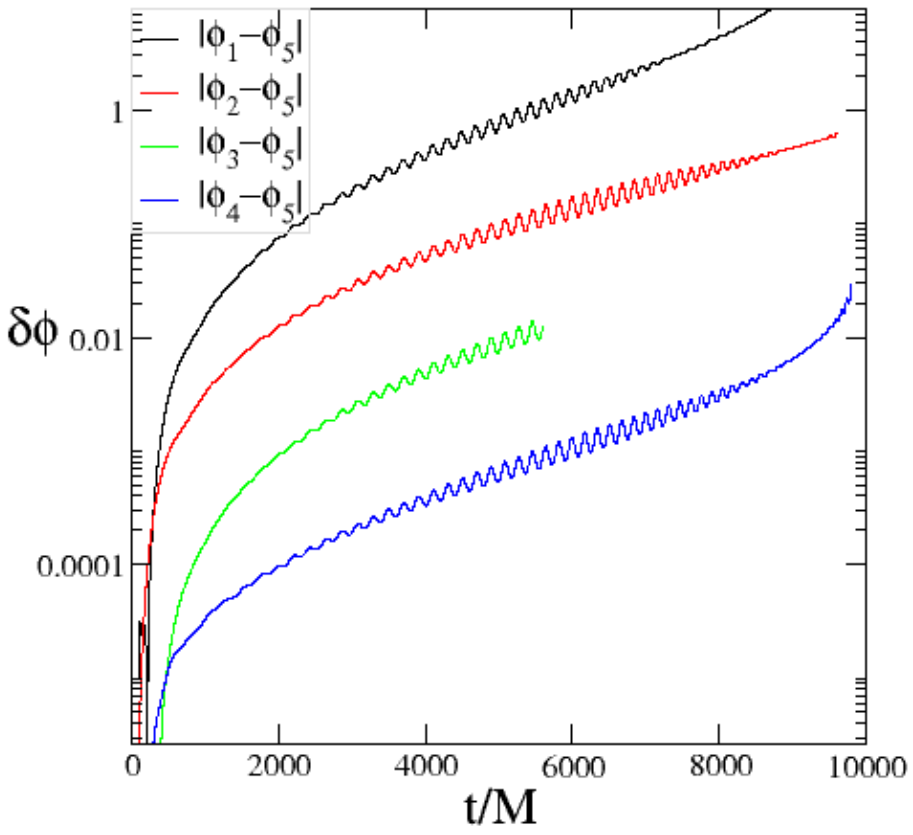
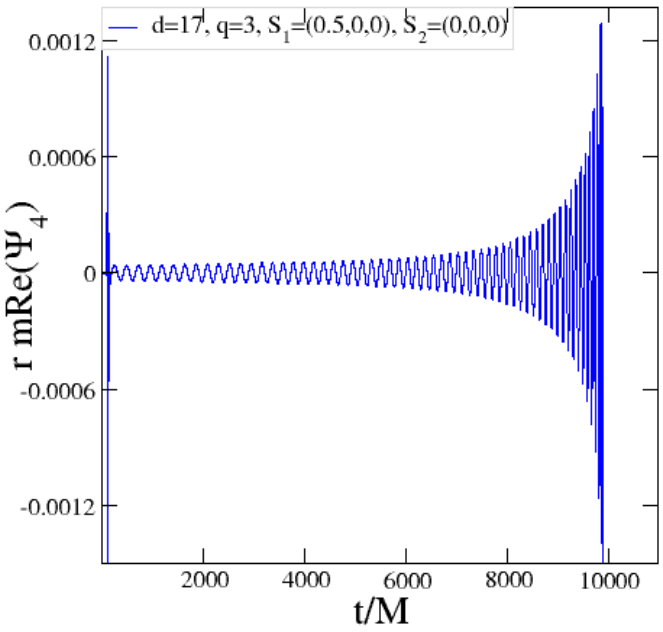


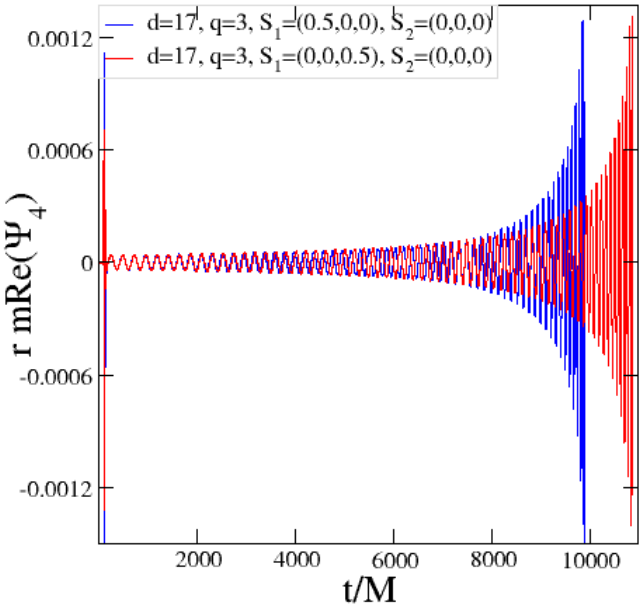




- Current δϕ: 0.03 radians







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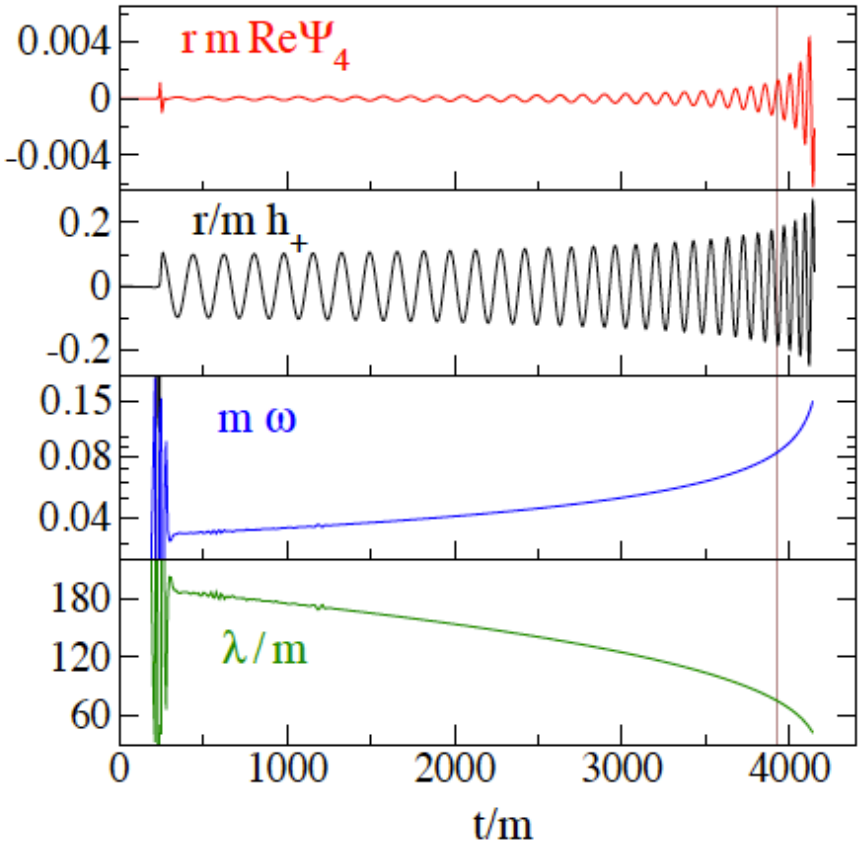
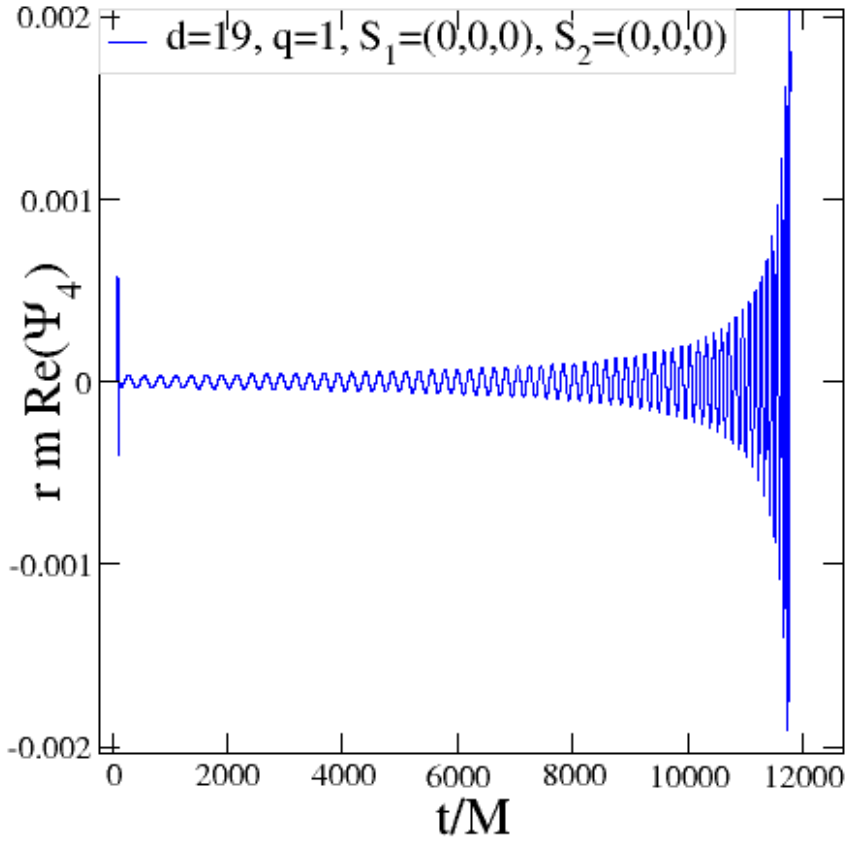
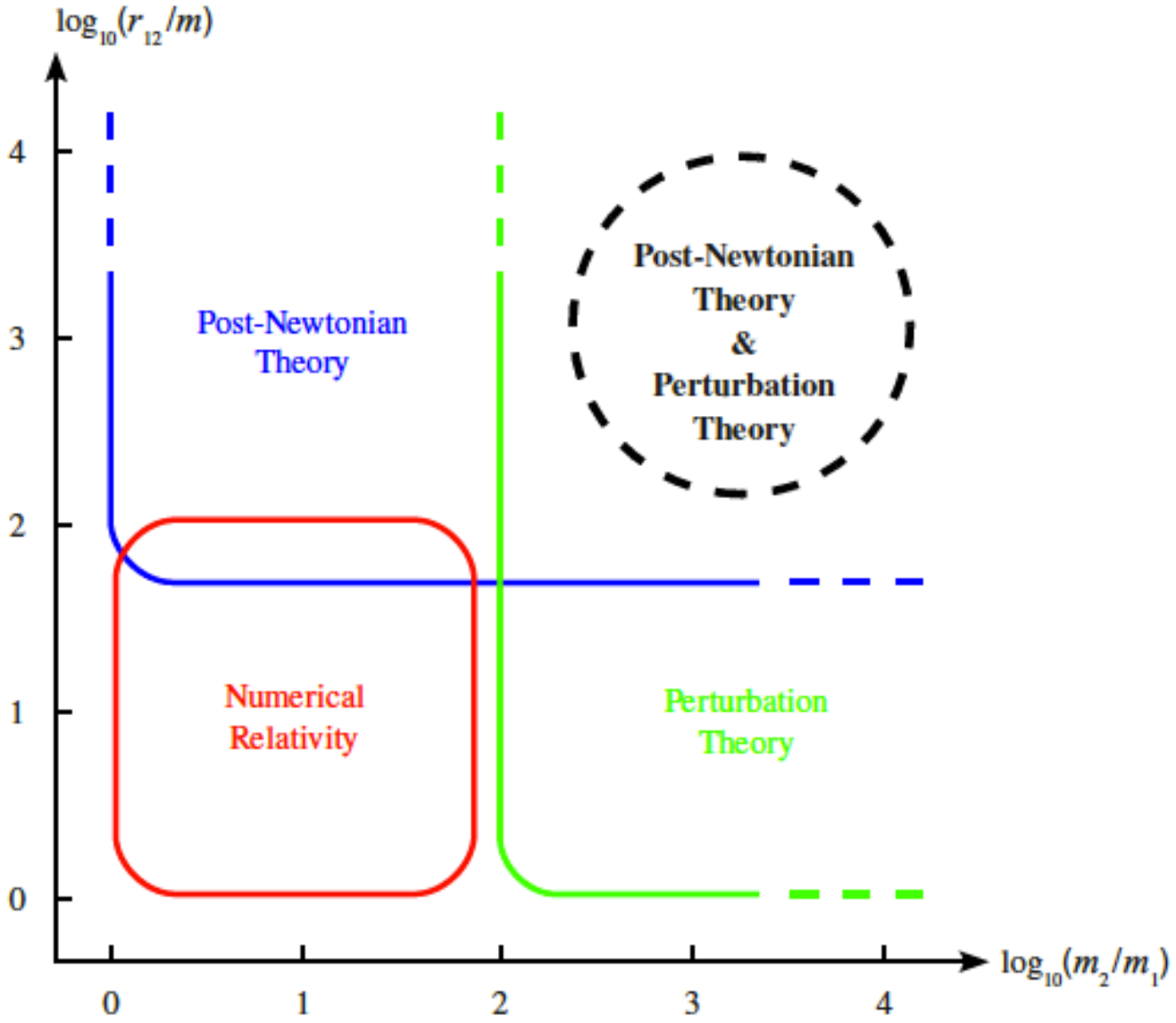
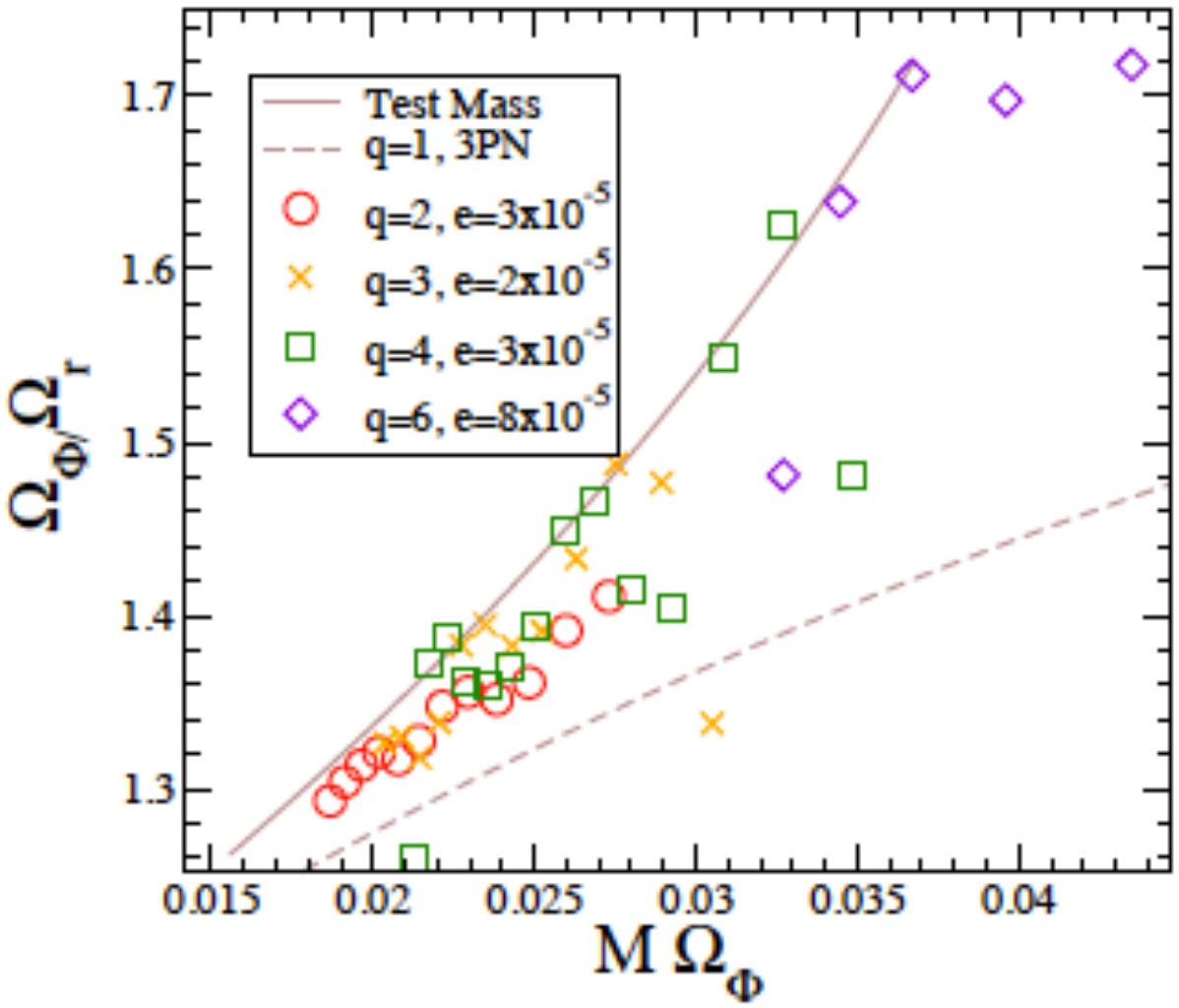




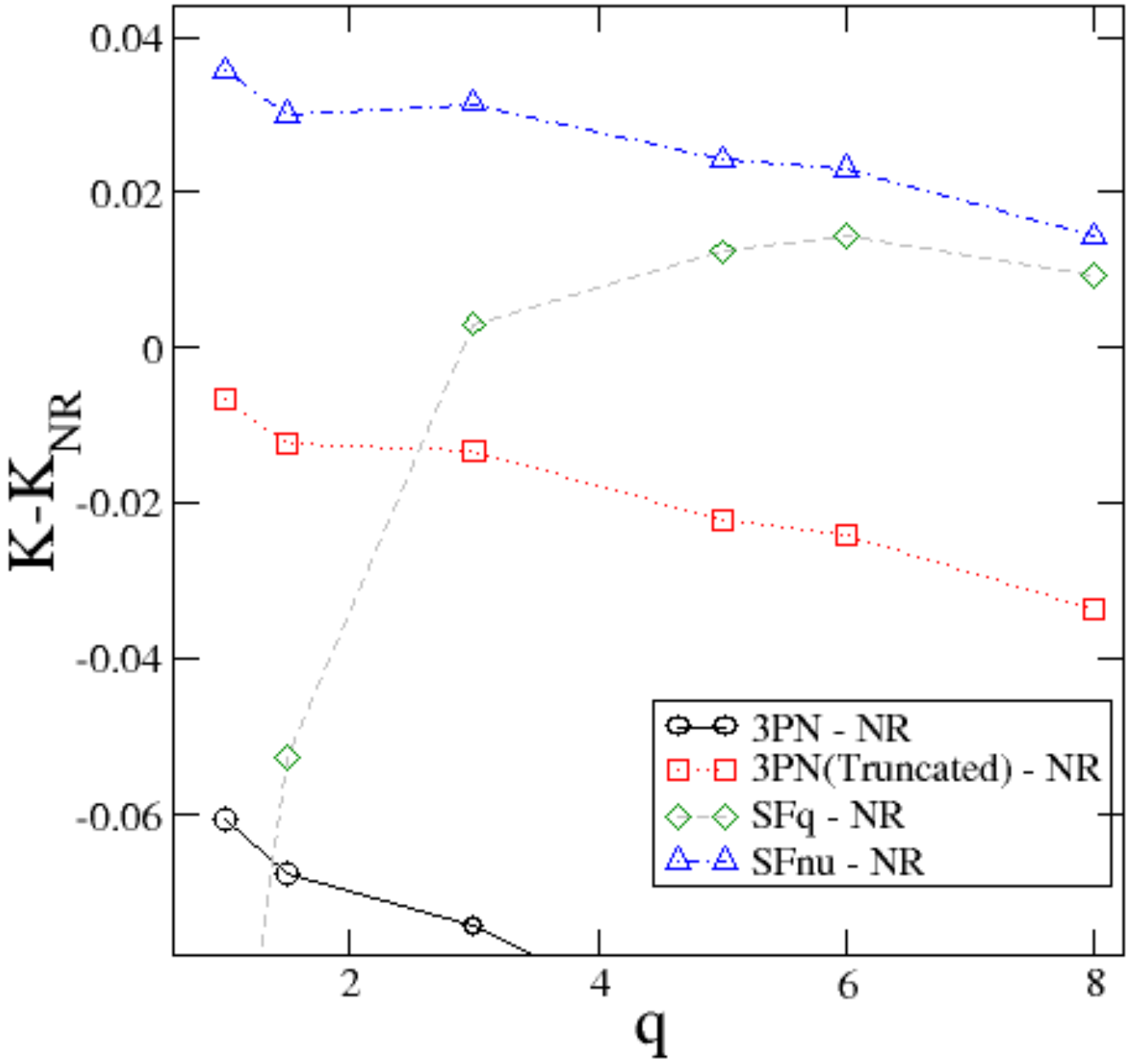
Long inspiral are important for parameter estimation, see MacDonald, Nissanke and Pfeiffer, arXiv:1102.5128

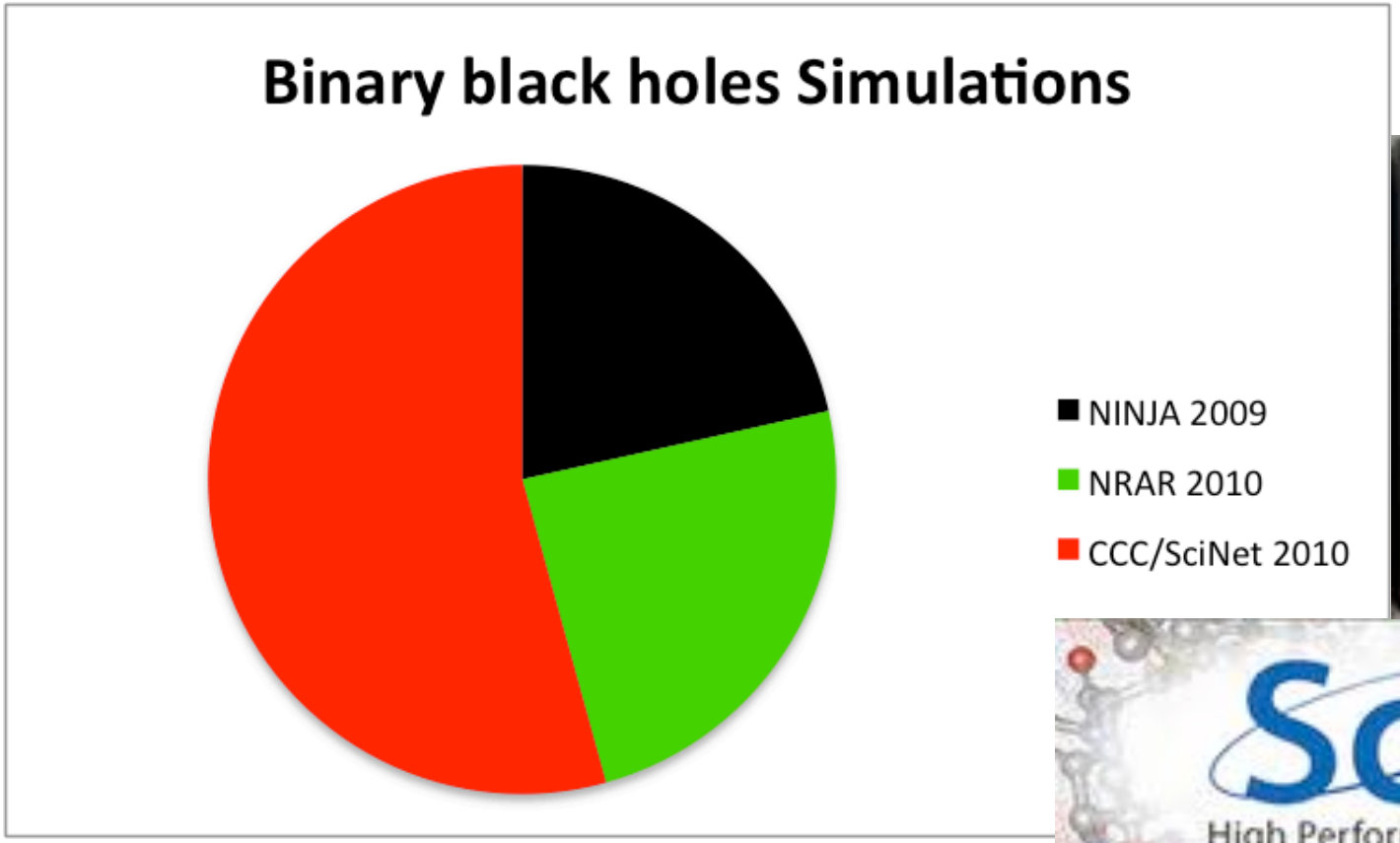


- From Blanchet et al. arXiv:1007.2614



More accurate measurements needed…
Compariosn to PN, self-force prediction…

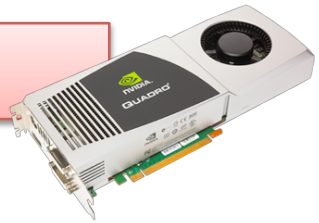

0.04
0.02
0
-0.02
-0.04
-0.06
K-K_NR
2
4
6
8
q
3PN - NR
3PN(Truncated) - NR
SFq - NR
SFnu - NR

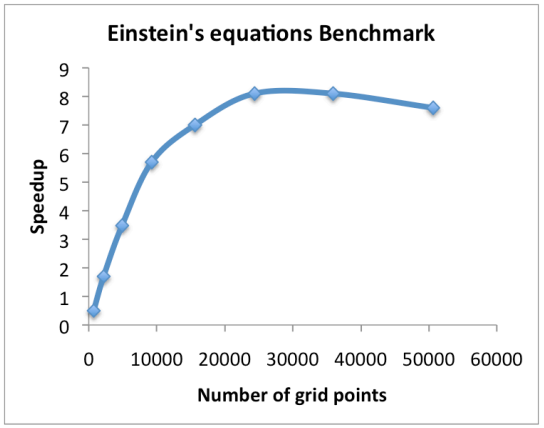


SciNet
High Performance Computing

- Challenge:
  - Need many simulations
  - Each one is costly

CUDA version of SpEC





- Effective method to reduce eccentricity, and to start with small eccentricity
- Explore eccentricity reduction for larger spins
- Mergers…
- Waveforms…
- Compare Spin effects to PN
- …