TRACKING THE PRECESSION OF BINARY BLACK HOLES

Patricia Schmidt (Cardiff University)

06.04.2011

Binary Black Hole Mergers

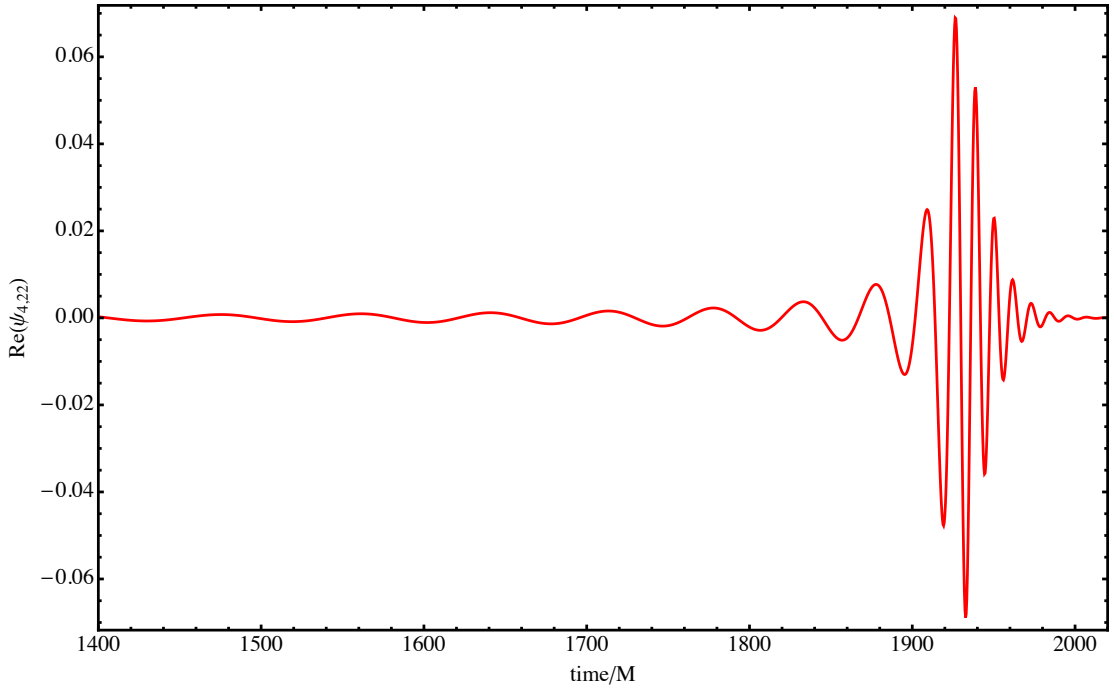
- Most promising sources of gravitational waves
- Characterised only by mass ratio q and spins
  - Geometrical units: total mass does not characterise waveform
- Accurate complete waveforms needed for GW detection and parameter estimation
  - Early inspiral modelled by PN
  - Late inspiral, merger & ringdown → Numerical Relativity

NR waveforms

- Evolve full Einstein equations numerically:
  - Obtain a complete solution without simplifications or assumptions
  - Calculate the gravitational wave signal from the Weyl scalar $\Psi_4 = \sum_l \sum_{m=-l}^{l} \Psi_{4,lm} {}^{-2}Y_{lm}(\theta,\varphi)$
    - Mode decomposition *always* performed w.r.t. a fixed coordinate frame
  - Accurate GW modes for the late inspiral, merger and ringdown

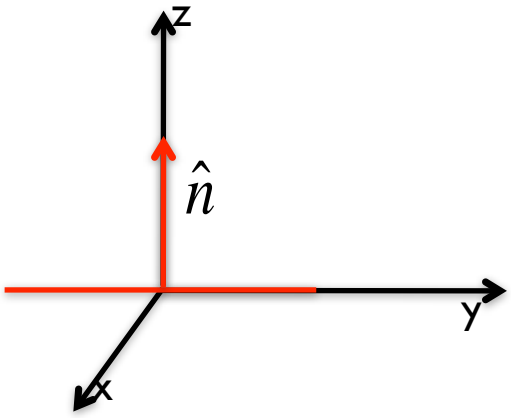
NR waveforms

- Evolve full Einstein equations numerically:
  - Obtain a complete solution without simplifications or assumptions



Mode-mixing

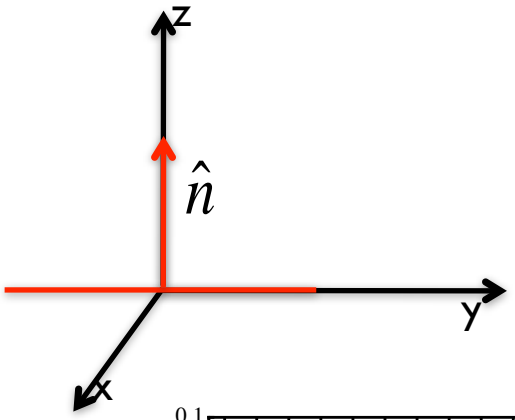
- Equal-mass non-spinning binary:

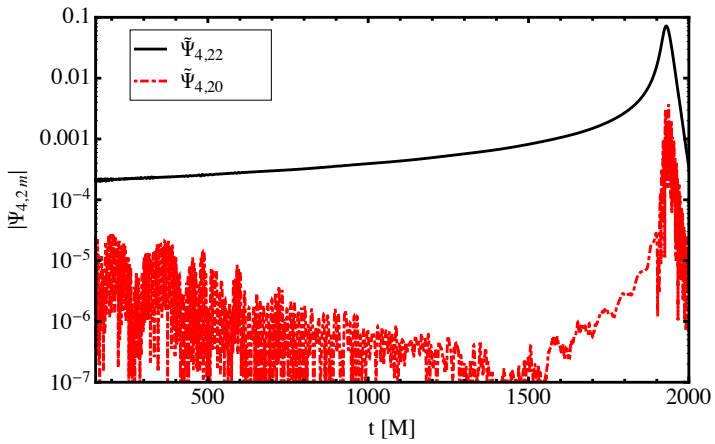


  - "Natural" orientation → only $(2,\pm 2)$-modes

Mode-mixing

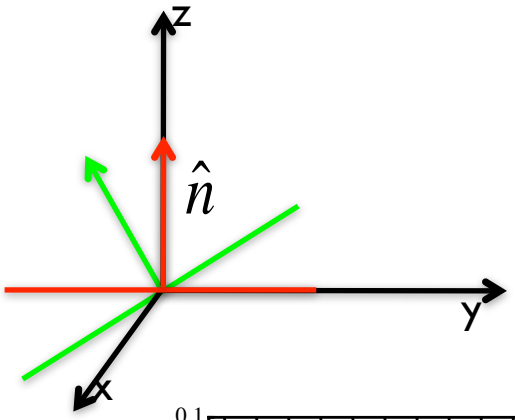
- Equal-mass non-spinning binary:
  - "Natural" orientation → only (2,±2)-modes

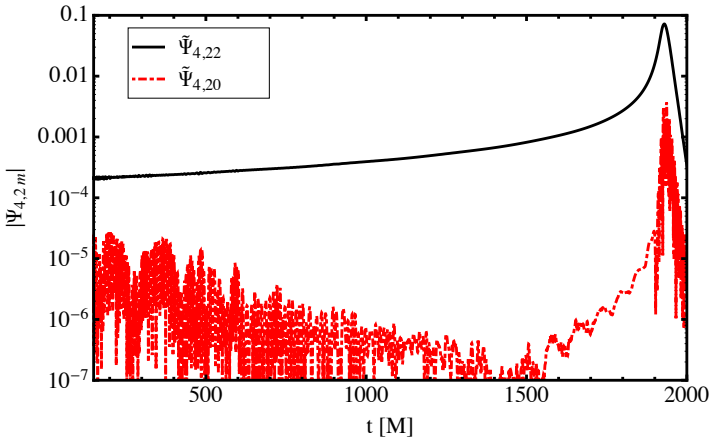




Mode-mixing

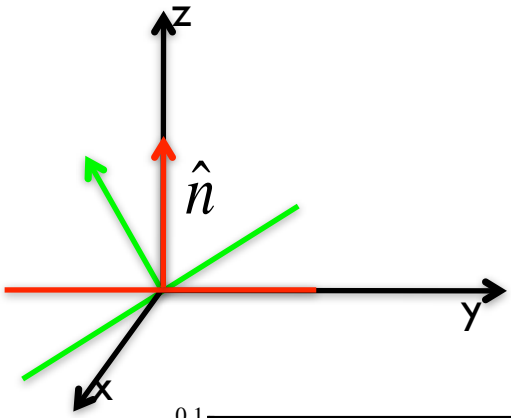
- Equal-mass non-spinning binary:
  - "Natural" orientation → only (2,±2)-modes



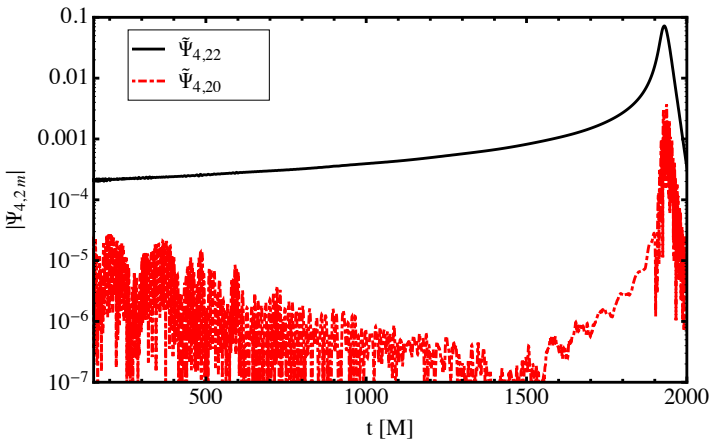


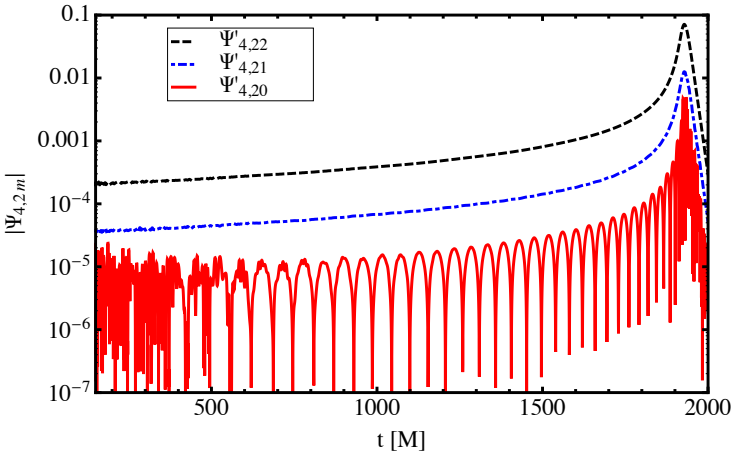
Mode-mixing

- Equal-mass non-spinning binary:



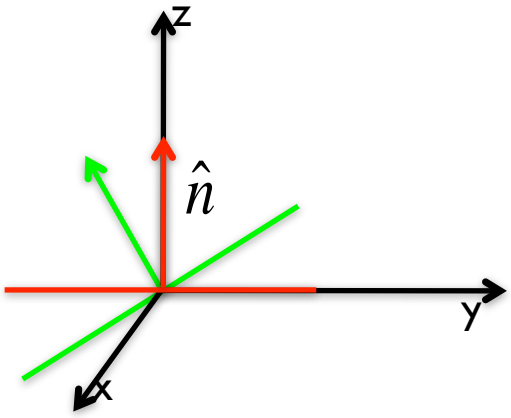
  - "Natural" orientation → only (2,±2)-modes
  - Relative inclination between xy-plane of fixed frame and orbital plane of motion yields "*mode-mixing*"





Mode-mixing

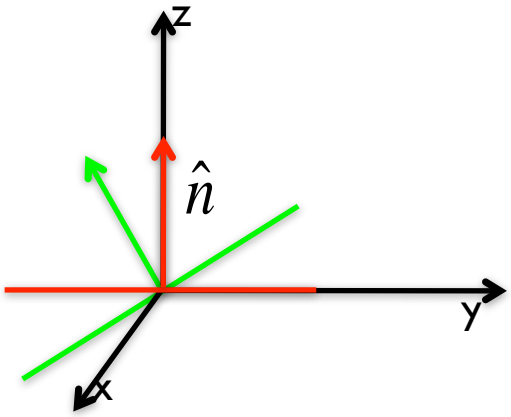
- Equal-mass non-spinning binary:



  - "Natural" orientation → only (2,±2)-modes
  - Relative inclination between xy-plane of fixed frame and orbital plane of motion yields "*mode-mixing*"

Mode-mixing

- Equal-mass non-spinning binary:

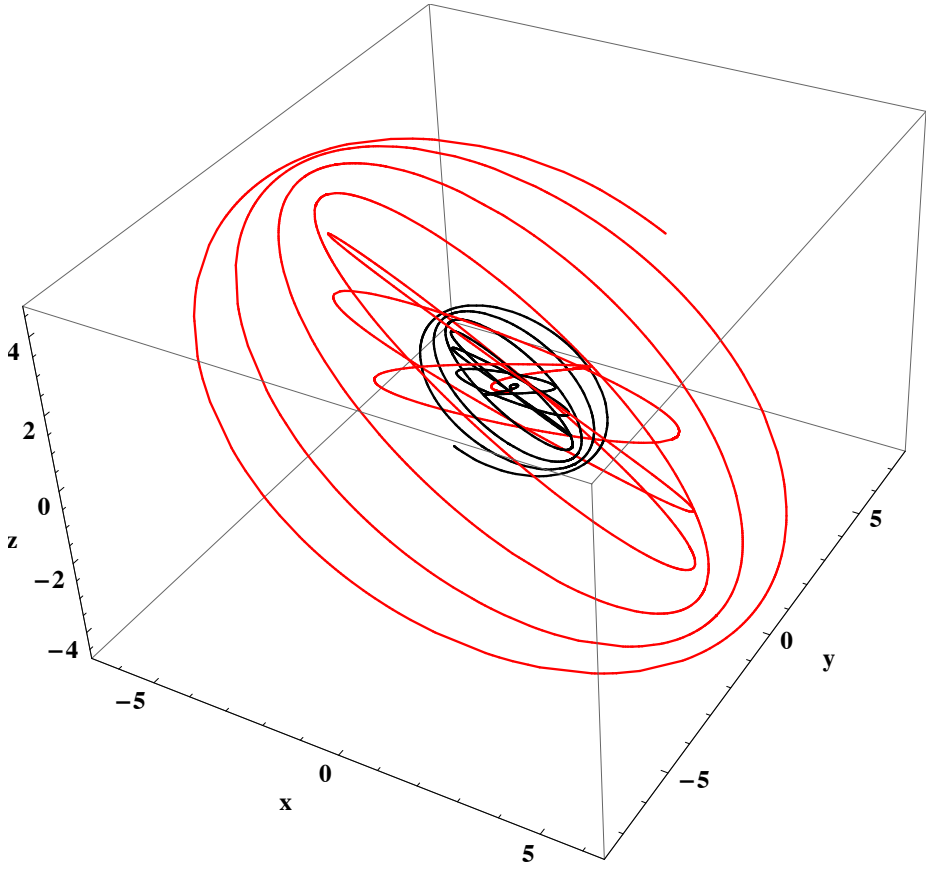


  - "Natural" orientation → only (2,±2)-modes
  - Relative inclination between xy-plane of fixed frame and orbital plane of motion yields "*mode-mixing*"

  - $\Psi_{4,22}$ tracks the motion in the xy-plane
  - Misalignment redistributes energy among other modes

Mode-mixing

- For precessing binaries amplitude modulations and extra oscillations are introduced as well



QA frame

? Can we disentangle the complex motion of the binary and simplify the signal ?

QA frame

? Can we disentangle the complex motion of the binary and simplify the signal ?

- If the orbital motion is confined to the xy-plane of the simulation frame, the $(2,\pm 2)$-modes are the dominant ones and their coefficients are maximised

QA frame

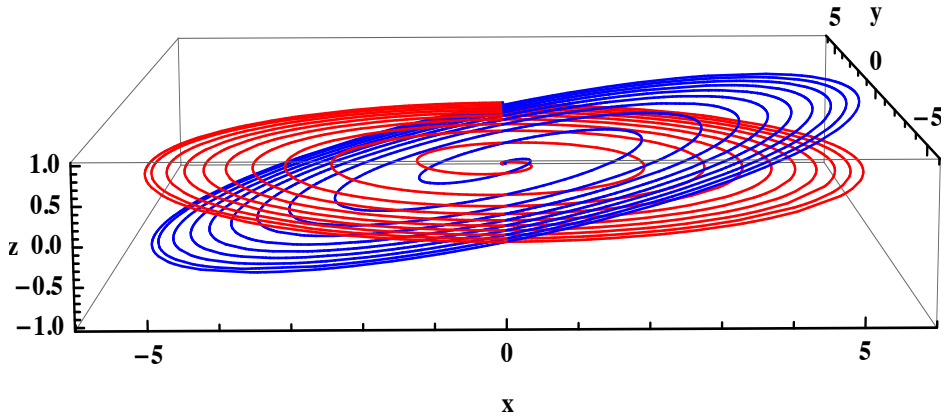
? Can we disentangle the complex motion of the binary and simplify the signal ?

- If the orbital motion is confined to the xy-plane of the simulation frame, the (2,±2)-modes are the dominant ones and their coefficients are maximised

- Apply rotation about two angles such that the (2,±2)-modes are maximised → *"quadrupole-aligned" frame*

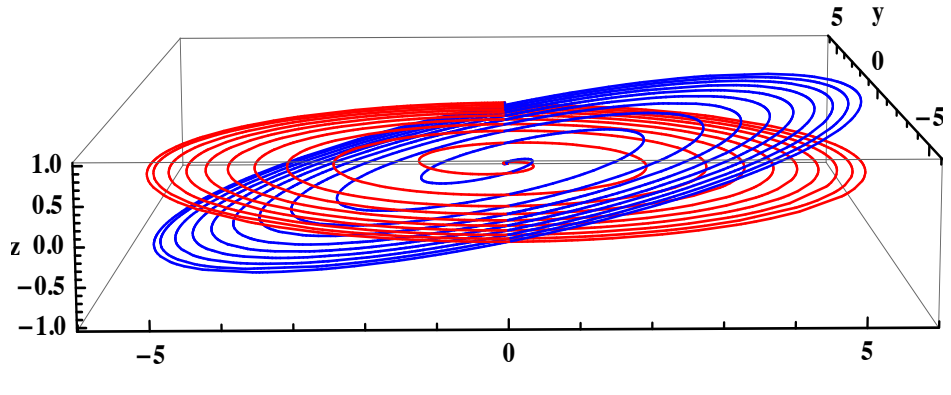
Tilt & twist

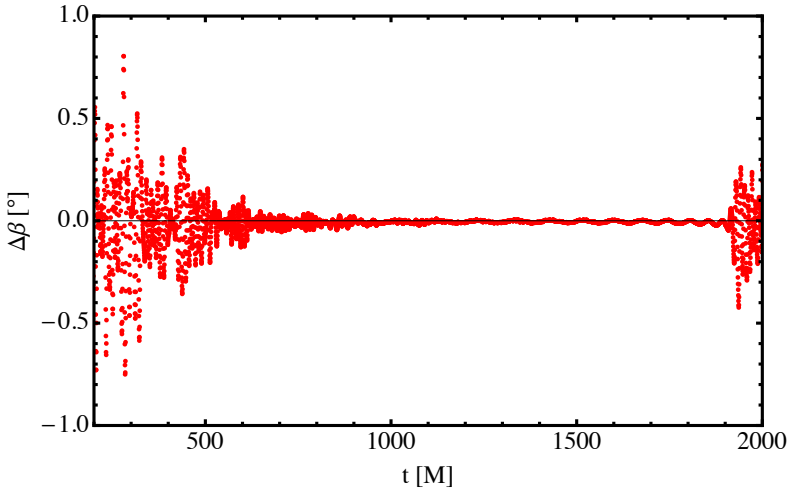
- Study case: $q=1$, $a_i=0$
  $\beta=10°$, $\gamma=25°$

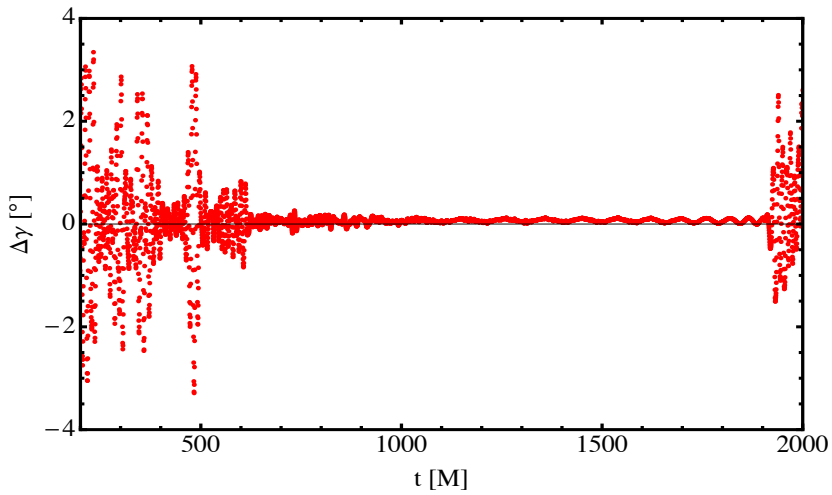


Tilt & twist

- Study case: $q=1$, $a_i=0$
  $\beta=10°$, $\gamma=25°$

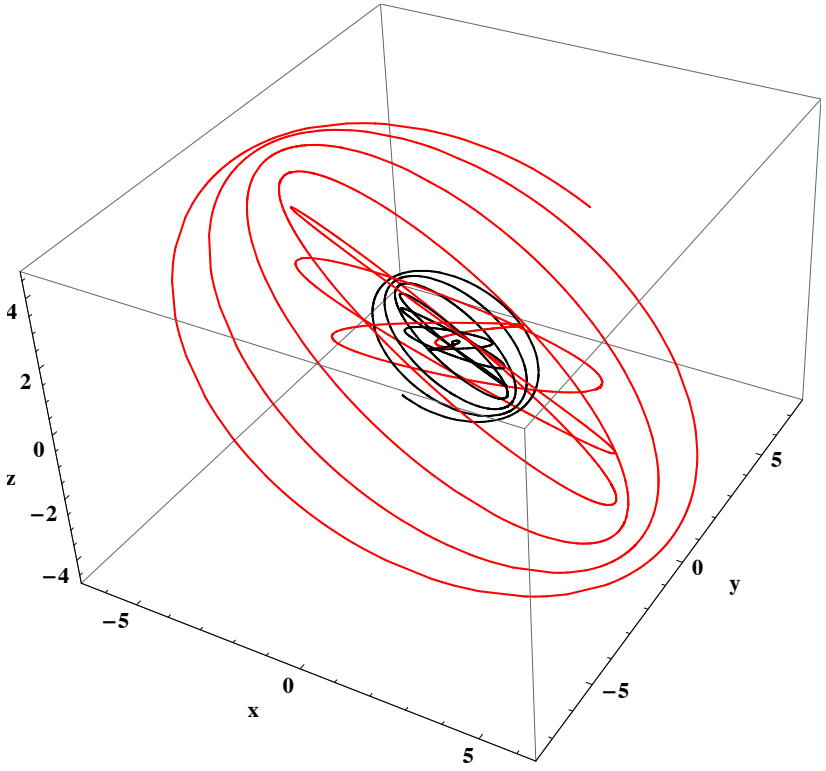






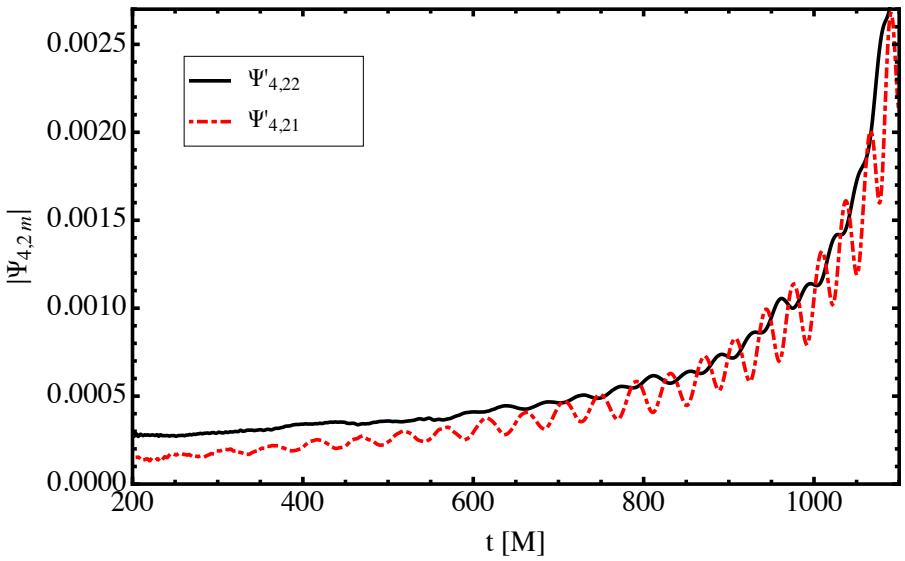
Precessing case

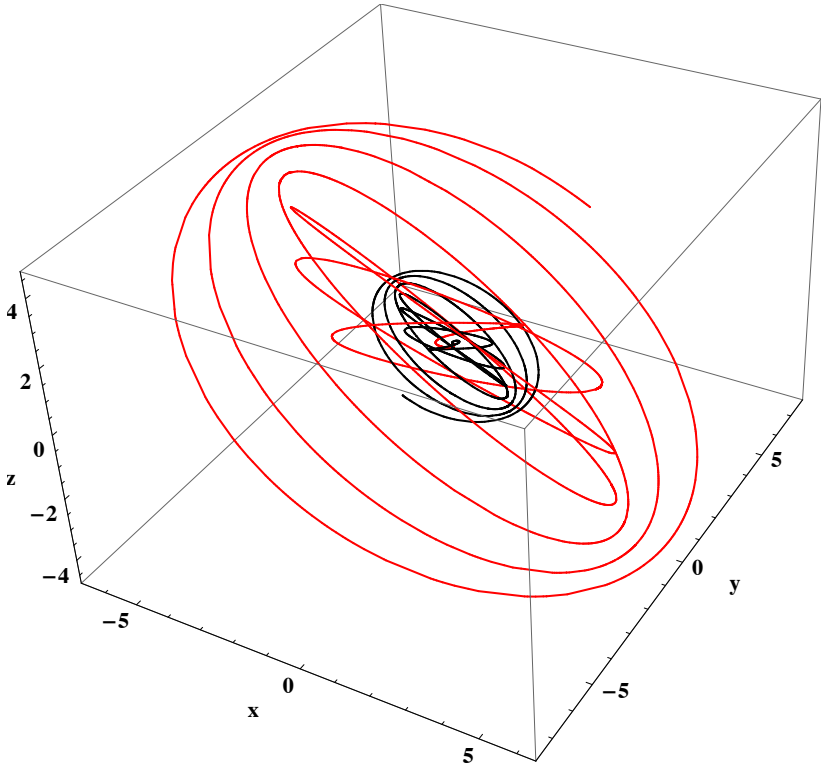
- Study case: q=3, a_1=0, a_2=0.75
- Significant precession expected ← $\vec{S}\cdot\vec{L}\neq 0$



Precessing case

- Study case: q=3, a_1=0, a_2=0.75
- Significant precession expected ← $\vec{S}\cdot\vec{L}\neq 0$



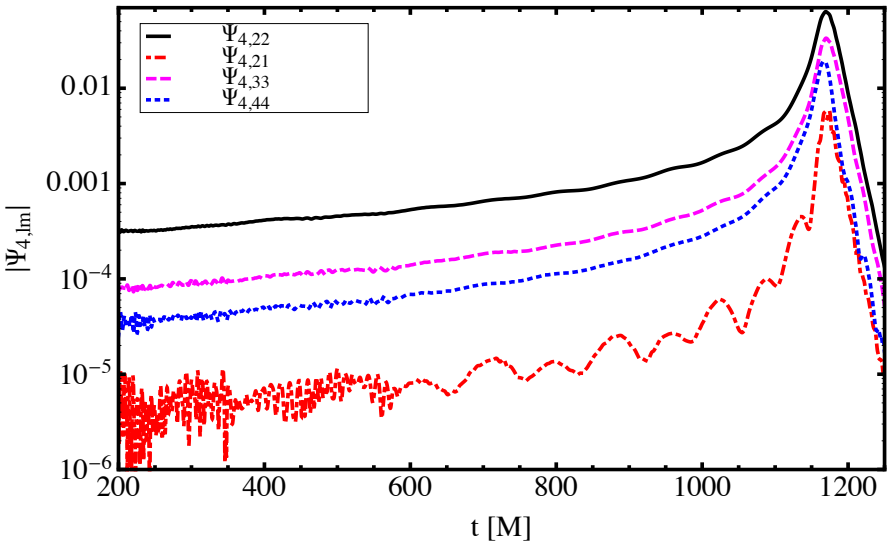


Results I

- Applied maximisation routine to track the precession of the orbital plane:

Results I

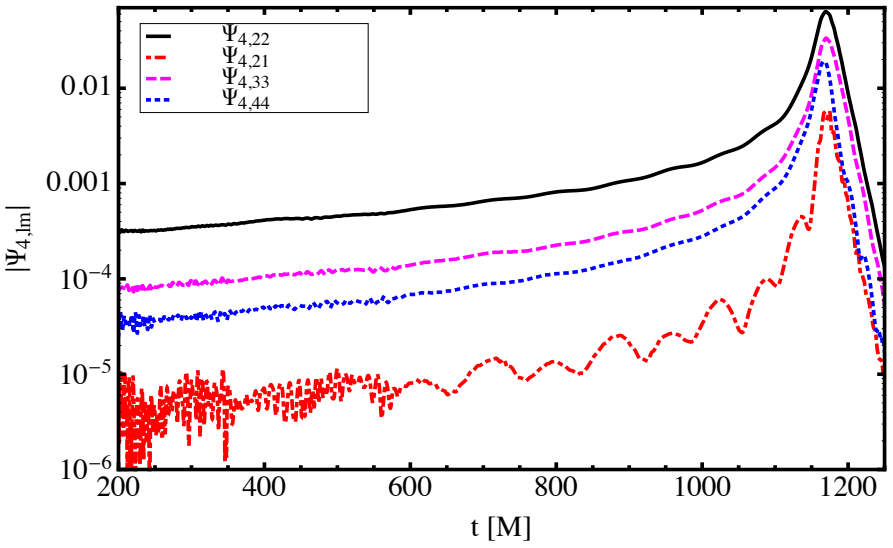
- Applied maximisation routine to track the precession of the orbital plane:



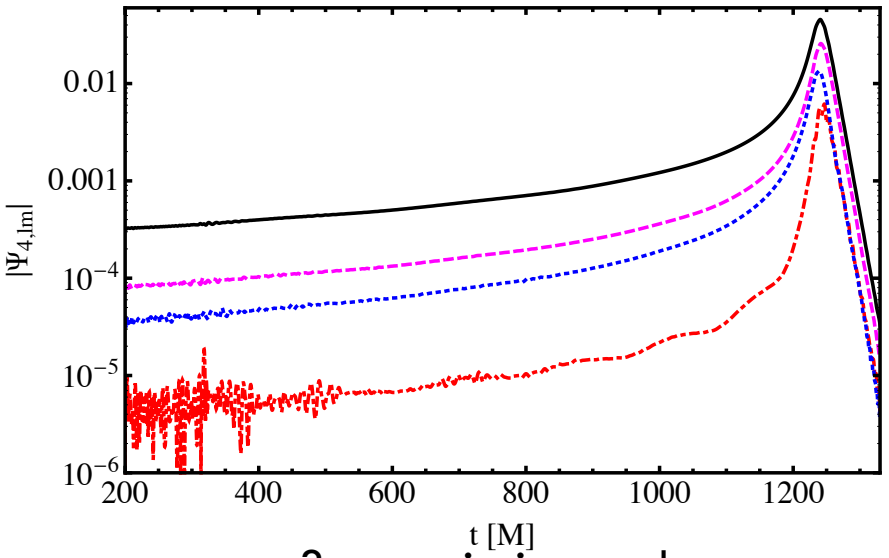
QA-modes

Results I

- Applied maximisation routine to track the precession of the orbital plane:



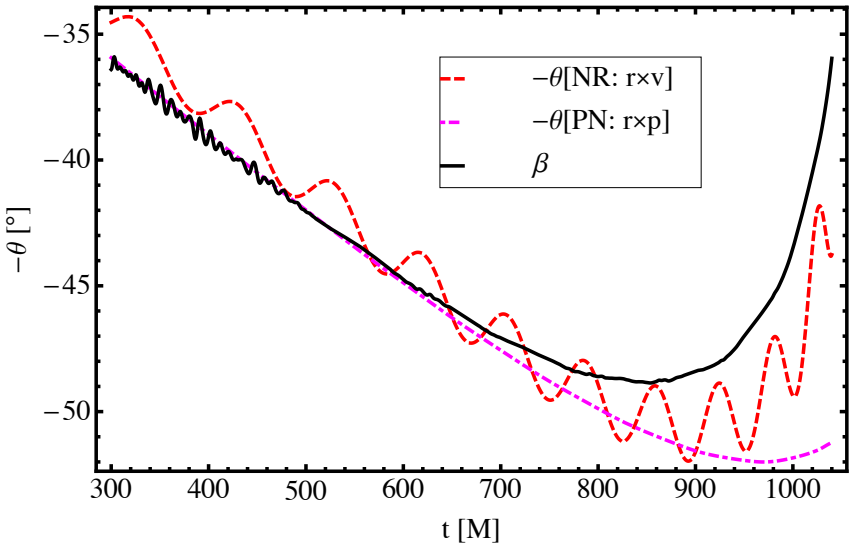
QA-modes

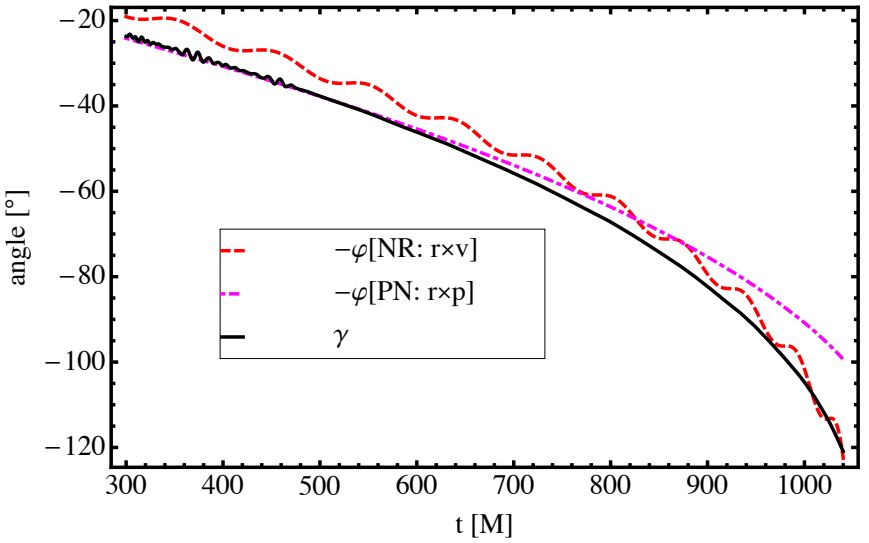


q3 non-spinning modes

Results II

- What direction are we tracking ?





- PN: predominant GW emission in the direction of $\vec{L}$
- Comparison suggests: we track orbital angular momentum

Summary

- Spins produce interesting features in the waveform
- Spin effects like the precession of the orbital plane can be disentangled to simplify the functional form of the signal
- Promising first step towards modelling precessing waveforms
- Details: arXiv:1012.2879v1 [gr-qc]

Future work

- Estimate the direction of the final spin $\vec{J}_{final}$
- Apply the procedure to PN waveforms
- Study cases with $\vec{S}\cdot\vec{L}\neq 0$
- Study cases with two spinning black holes
- Apply to analytic modelling of precessing binaries