Black hole induced spins from hyperbolic encounters in dense clusters (arXiv:2106.01436)

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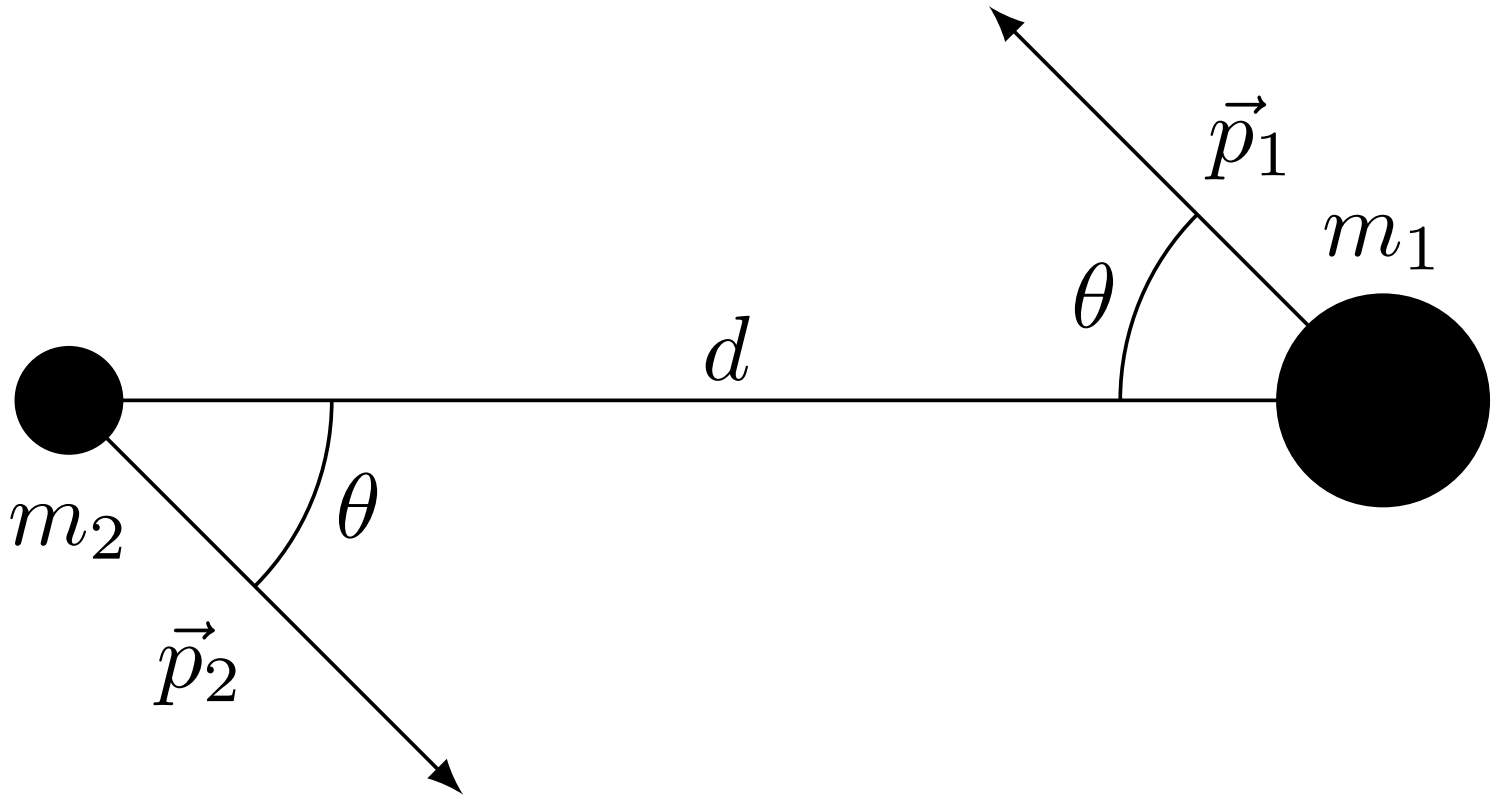
Introduction

- Aim of the work: study spin induction of initially nonspinning BHs within CHE.
- Based on the work of P.E. Nelson et al., Phys. Rev. D 100 (2019), done only for equal masses.
- Different approach:
  - Introducing different masses.
  - Study of the trends for different parameters with more detail.
  - Implications for real populations of BHs, particularly PBHs, which are formed without spin and in clusters.
- Numerical simulations done with the Einstein Toolkit.

Initial conditions

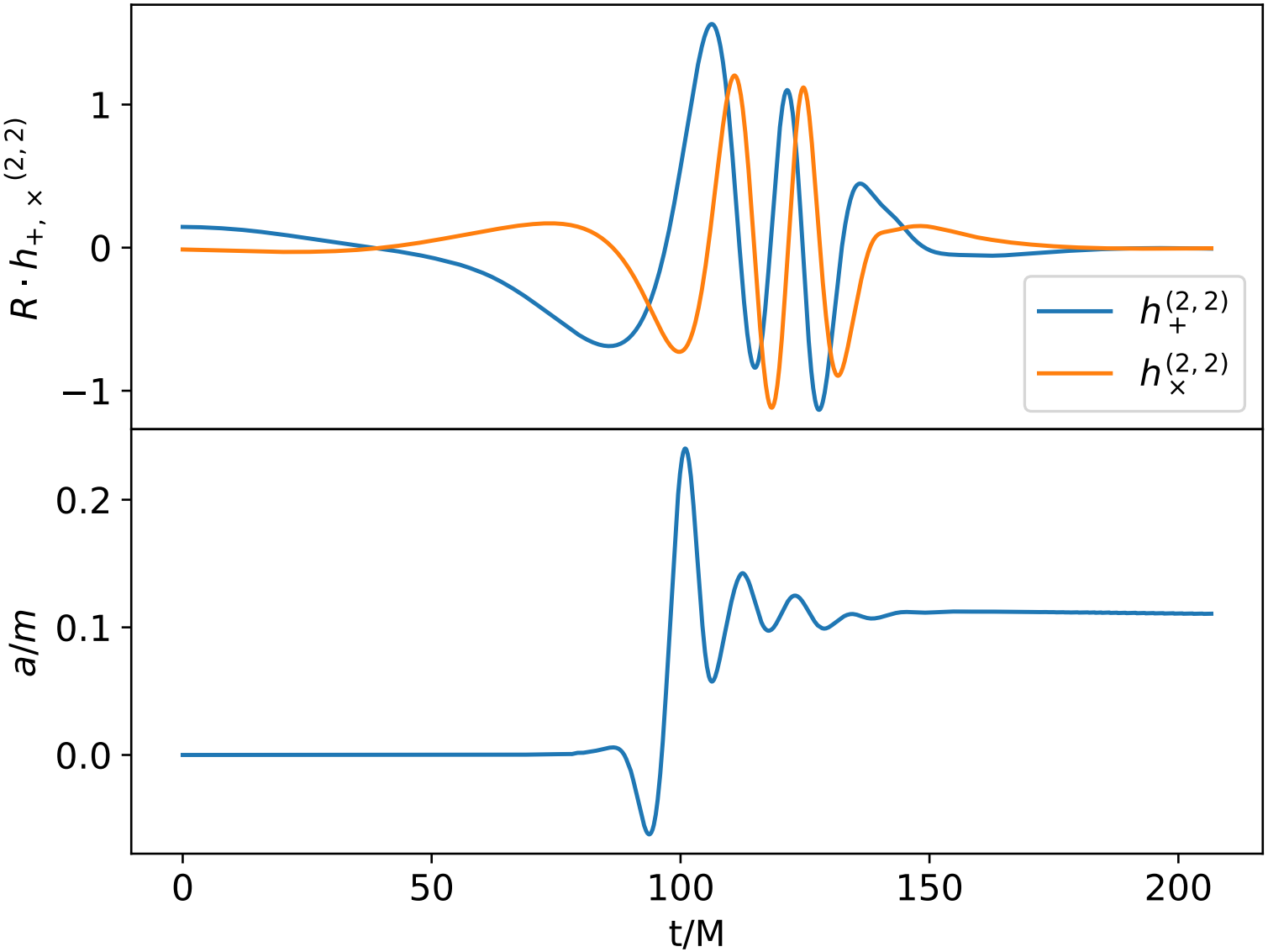


- Initially without spin.
- We fix $d = 100M$, $\vec{p}_1 = -\vec{p}_2$.
- Three free parameters: initial momentum $p = |\vec{p}_1| = |\vec{p}_2|$, incidence angle θ, mass ratio $q = m_2/m_1 \leq 1$.

Technical issues

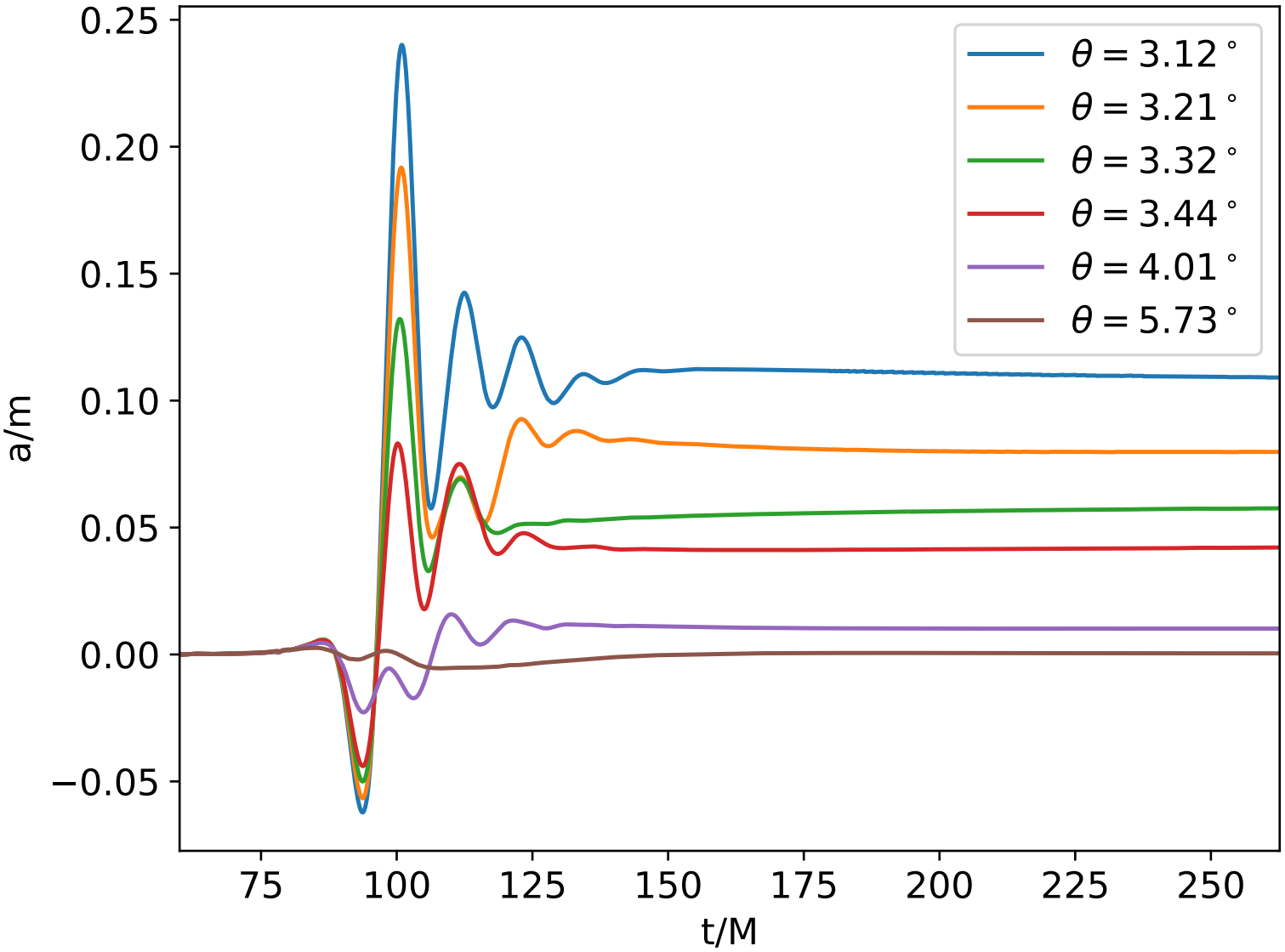
- Cactus, Carpet, TwoPunctures, McLachlan, AHFinderDirect, QuasiLocalMeasures, WeylScal4, etc.
- Hyperbolic encounters require more space than BBH $\rightarrow$ larger grid, more refinement, more computational power and time is required.
- Introducing $q \neq 1$ breaks a symmetry and needs more refinement around the small BH $\rightarrow$ more resources.
  - Problematic for $q \ll 1$: we focus on $0.7 \leq q \leq 1$.
- We focus on the dimensionless spin parameter $\chi = a/m$.

Typical output of a simulation



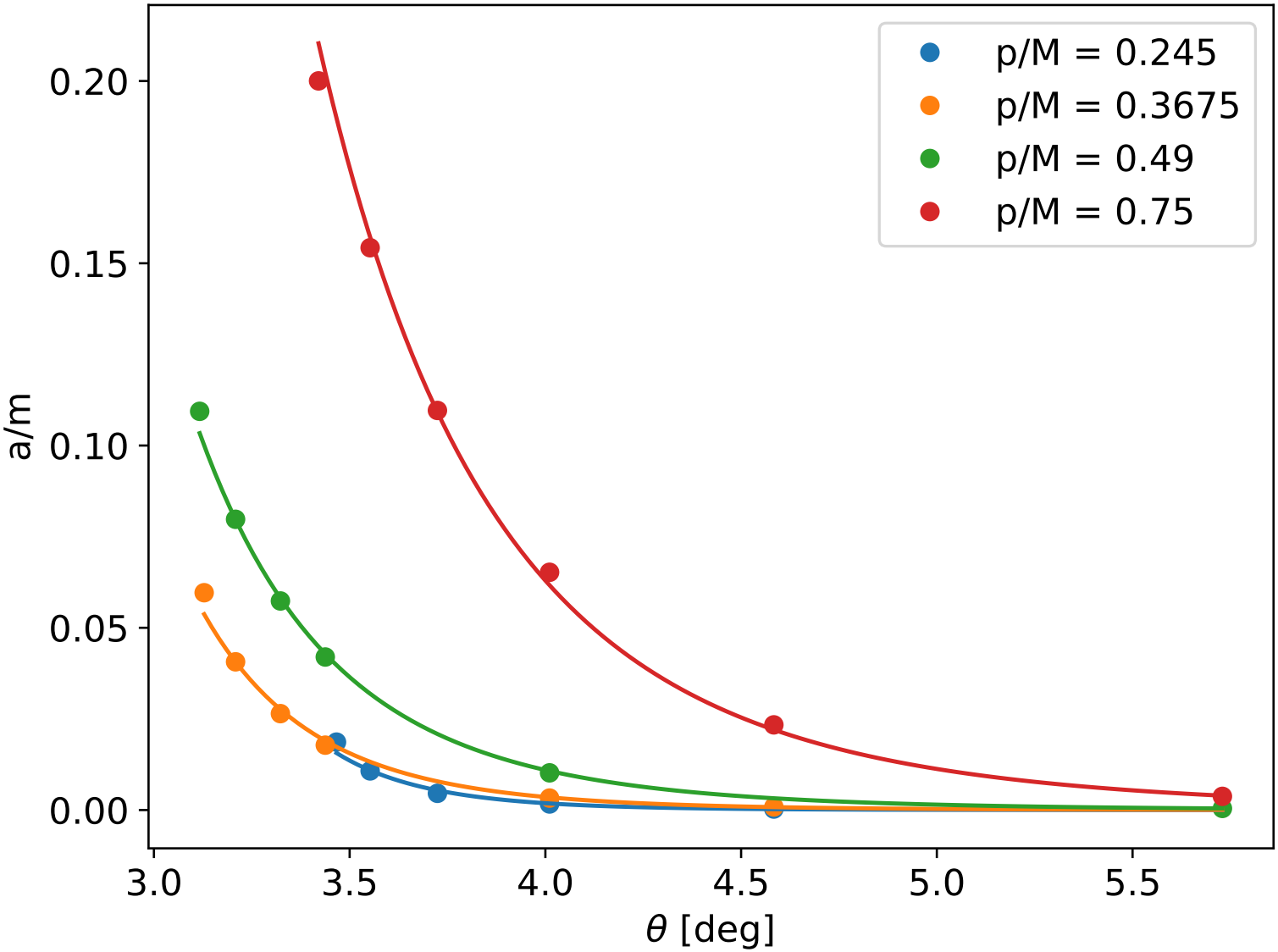
Varying θ, fixed p, $q = 1$

Spin evolution vs time



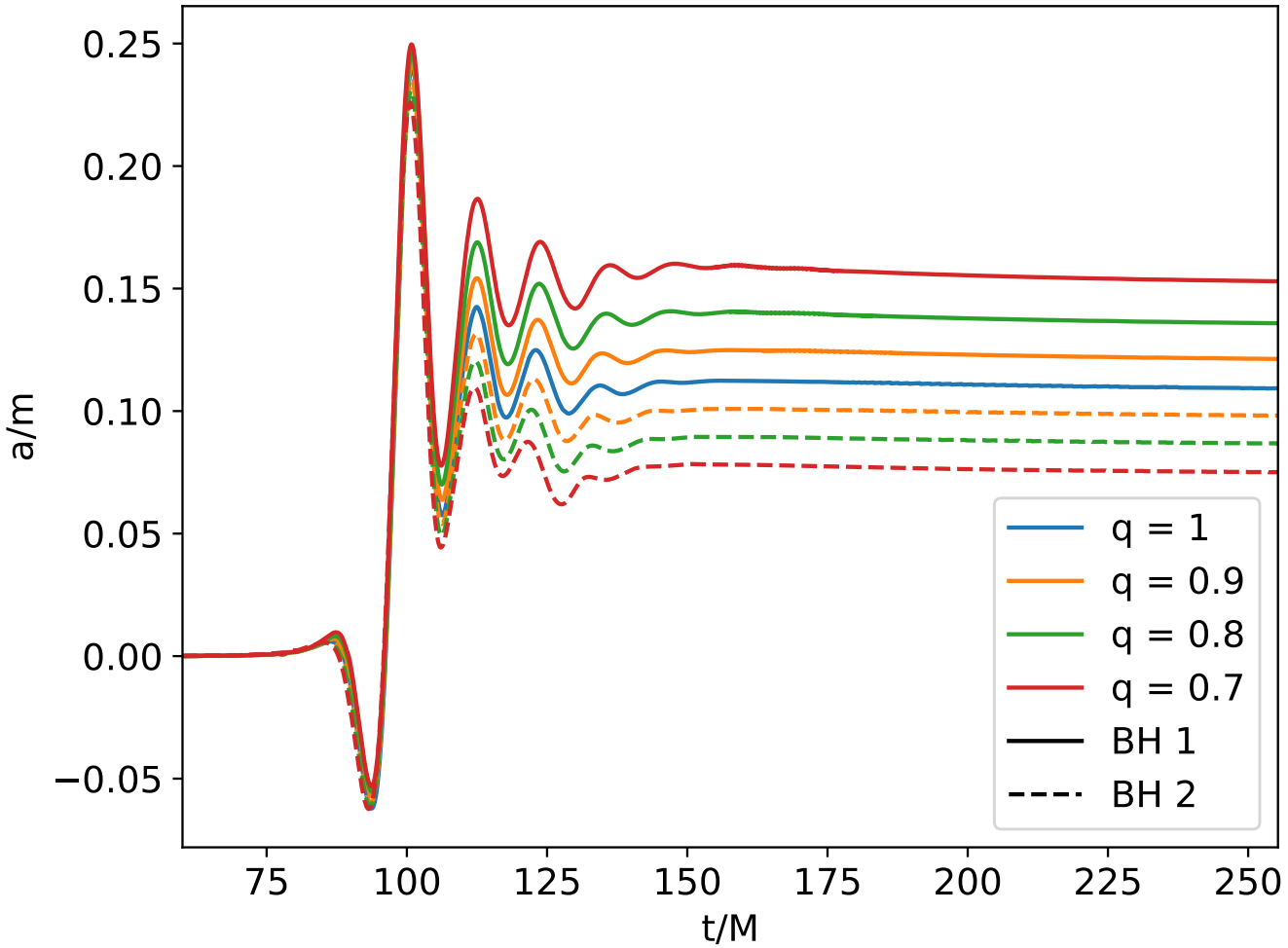
Varying θ, fixed p, $q = 1$

Final spins vs θ for different p



Varying q, fixed p, $\theta = \theta_{\text{min}}$

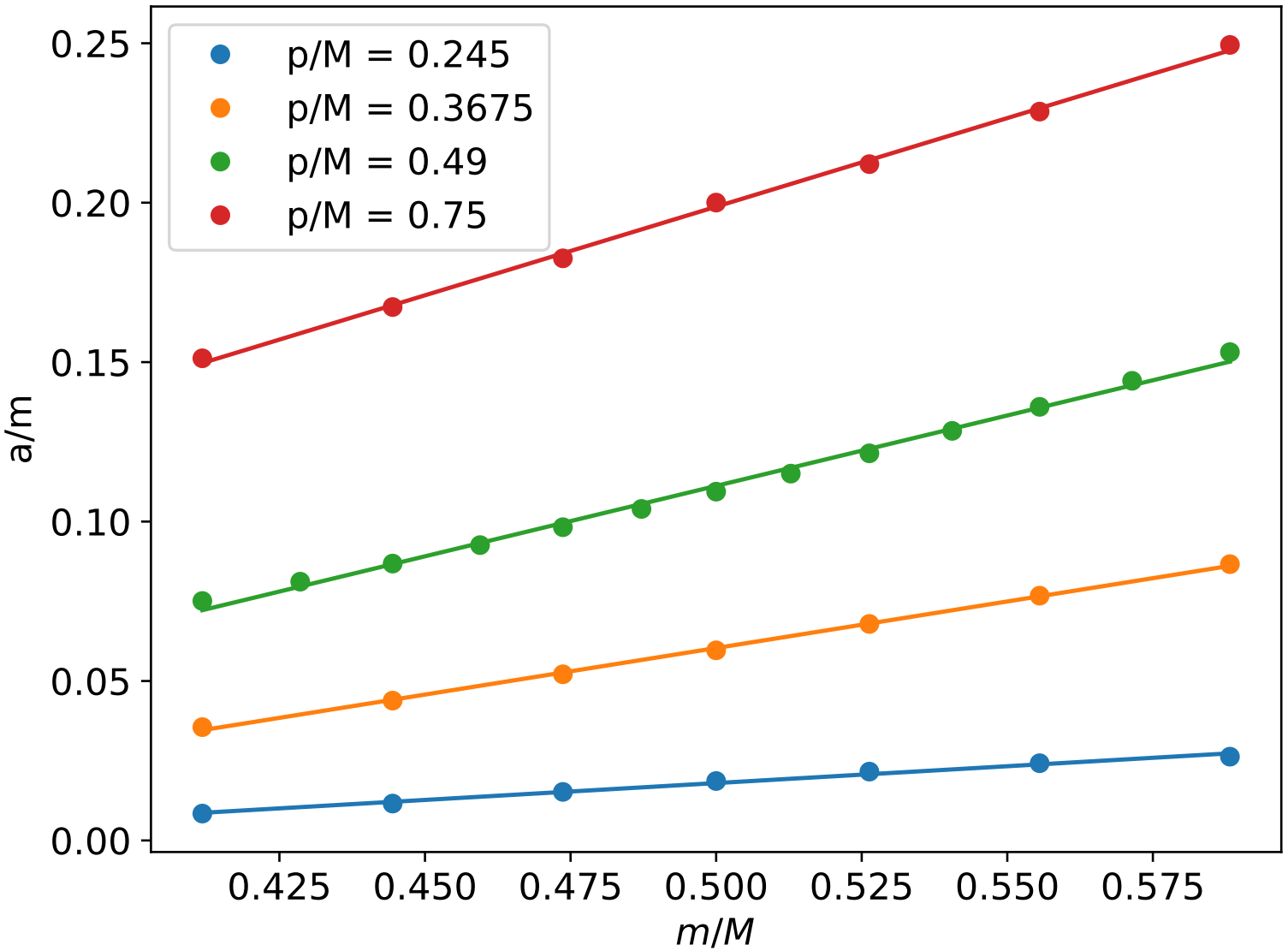
Spin evolution vs time



- Different spins for each mass: *the highest one is induced on the most massive BH*!

Varying q, fixed p, $\theta = \theta_{\min}$

Final spins vs mass for different p



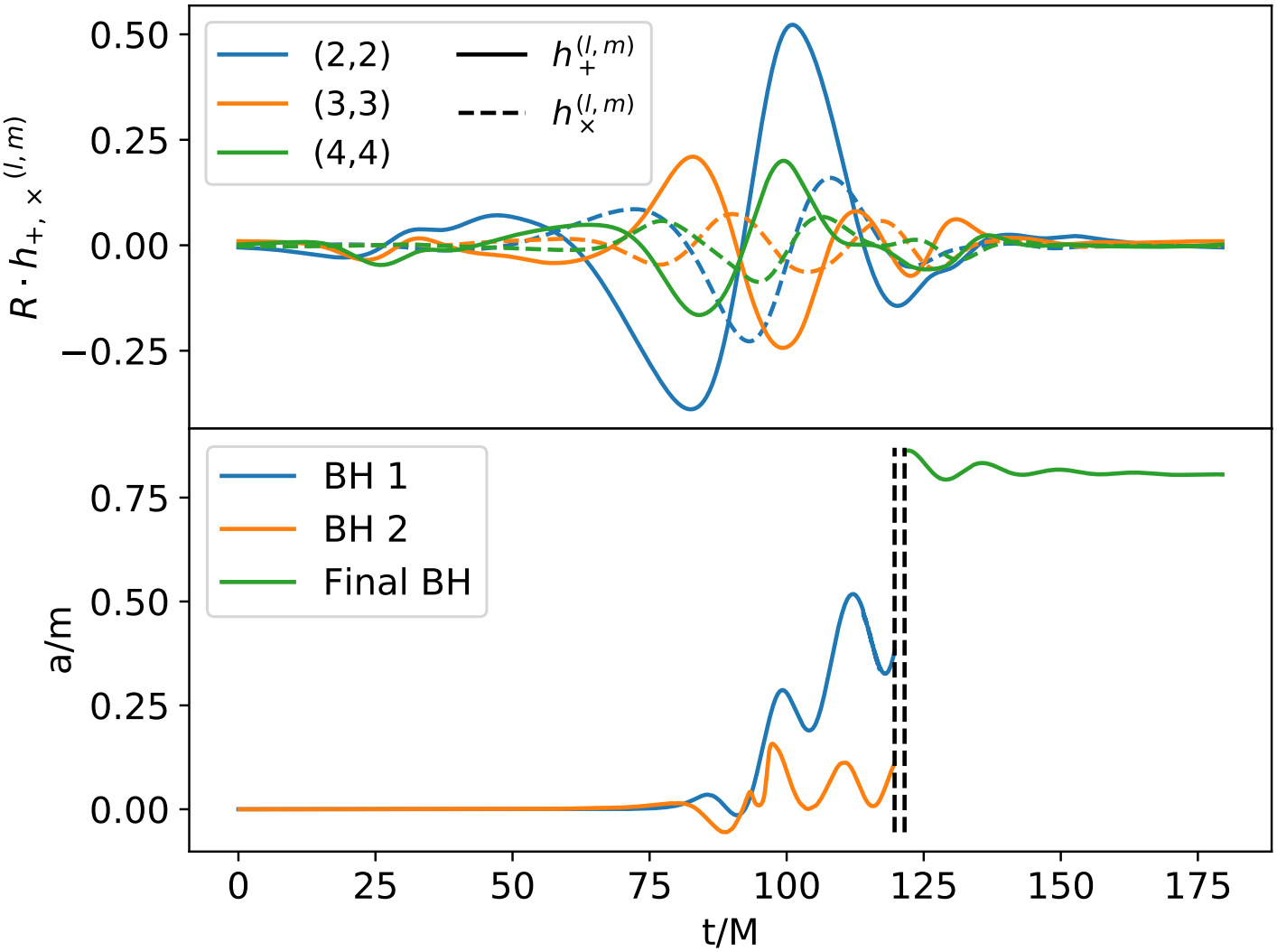
Some words on the trends and analytic estimation

- Varying θ. Good fits to (negative) power laws. More negative exponents for lower momenta.
- Varying q. Good fits to straight lines for the $\chi - m$ curve. Greater slopes in relative terms for lower momenta.
- A weak-field analytic approach can predict the spin decrease with θ and that the higher spin is induced on the most massive BH for the $q \neq 1$ cases.
- However, it fails to predict the trends quantitatively. Expected since PPN(4) formalism would be required for accurate predictions.

The $q = 0.1$ simulation

- Much more time consuming due to the extra refinement levels required.
- Typical times for the simulations on an HPC cluster:
  - $q = 1$: few days.
  - $0.7 \leq q \leq 1$: $\sim$ a week.
  - $q = 0.1$: $\sim$ a month.
- Center of mass gets displaced a lot $\rightarrow$ need for corrections when measuring Weyl scalar from spheres (necessary for strain computation).
- Drastic change of limiting angle between hyperbolic and non-hyperbolic events ($\theta_{\rm min}$).
- Simulations expected to produce a CHE end up producing a merger!

The $q = 0.1$ simulation



- We confirm $\chi_1 > \chi_2$ also for low q.
- Note the high spins before the merger!

Final remarks

- Spin induction effect is not lost for $q \neq 1$ simulations.
- When $q \neq 1$, highest spin induced on most massive BH.
- Weak-field approximations clearly insufficient for such strong CHE.
- Two initially nonspinning BHs can acquire relevant spins before they merge. Careful with parameter estimation from real GW events! The estimated initial spins could have been lower originally.
- Viable spin induction mechanism for PBH (initially nonspinning), which are clustered and produce lots of CHE. Study of spin distribution for future work.

Thanks for your attention!

Questions?