Dynamics of Mixed Binaries

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Outline

- Motivation(s)
- Previous Work
- Recent Results
- Future Plans

Motivation(s)

- Dynamical details of mergers unknown
  - hard to observe directly
  - equation of state (EOS) and structure of neutron stars (NS) not known exactly
- Gravitational wave signal expected to be visible: expected detection rate of > 1/y (advanced detectors)

Previous Work - Overview

Typical binary systems in GR:

- Binary black hole systems (BBH)
- Binary neutron star systems (BNS)
- Neutron star - black hole systems (BHNS)

	BBH	BNS	BHNS
General Relativity	X	X	X
Hydrodynamics		X	X
Singularity problems	X	?	X

$\longrightarrow$ need experience from BBH and BNS simulations

Previous Work - Newtonian

First studies: Newtonian physics:

- Zwart et al. (1998), analytical
  Stable mass transfer from NS to BH
- Janka et al. (1999), numerical
  Short mass transfer (few cycles) for mass ratio $\gg 1$
- Lee et al. (1999), numerical
  Mass transfer only in certain cases

Newtonian studies with relativistic modifications (Paczynsky)

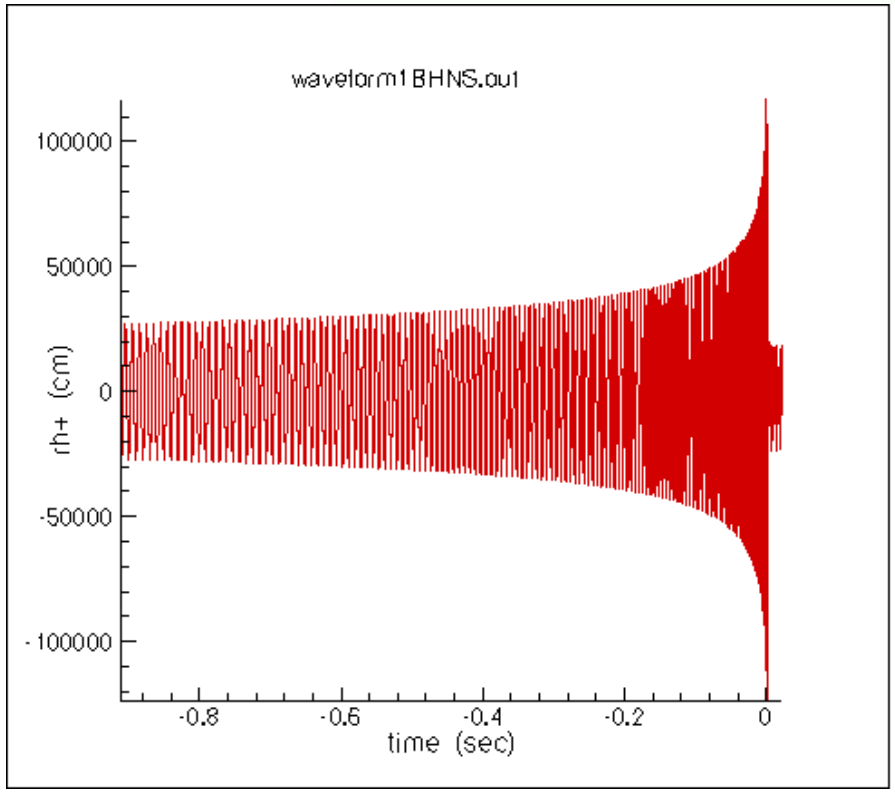
- Rosswog et al. (2005), numerical
  Complete disruption, no stable mass transfer

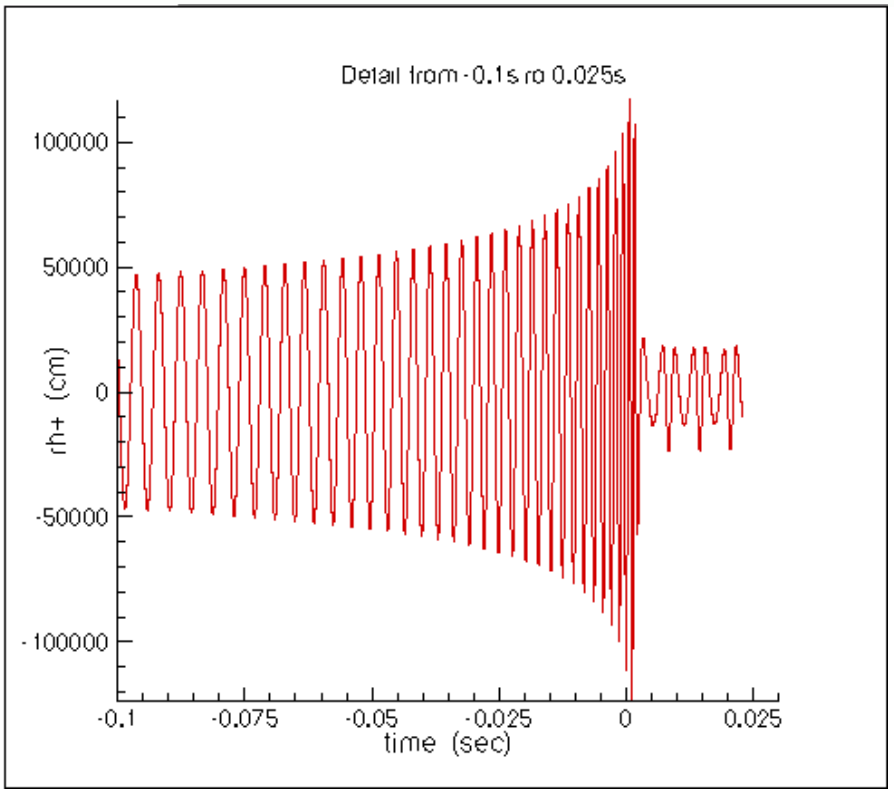
Previous Work - Relativistic

Relativistic studies:

- Baumgarte et al. (2004), Taniguchi et al. (2005), num.
  No discuption before merger, however: limited to big BH/NS mass ratios, quasi-stationary sequence
- Bishop et al. (2005), numerical
  Full evolution, but only short-term
- Miller et al. (2005), analytical
  Prompt merger for $M_{NS} < M_{BH}$ and slowly spinning BH because of angular momentum loss due to GW
- Sopuerta et al. (2006), numerical
  Full evolution, but restricted to large mass ratios and/or large separations

Previous Work - Typical Waveform





Lee et al. (1999)

Recent Work - Setup

Used “tools” from other simulations:

- “3+1” split of GR
- Computational infrastructure: `Cactus`
- Mesh refinement: `Carpet`
- Conformal formulation of GR equations (`BSSN`)
- Formulation and implementation of hydrodynamics equations (Euler, HRSC): `Whisky`
- Analysis tools and vacuum excision technique

Recent Work - Setup

New “tools” for a BHNS simulation:

- Initial data for a BHNS system
- Excision of Hydrodynamics at BH horizons (Phys. Rev. D 71:104006), applied also to Neutron star collapse (Phys. Rev. D 71:024035)
- Special Gauge conditions for evolution

Recent Work - Initial data

Procedure:

- Specify sources (NS, BH), separation, velocities ect.
- Solve for constraint equation(s)
- Check for physical parameters

Contraint equations:

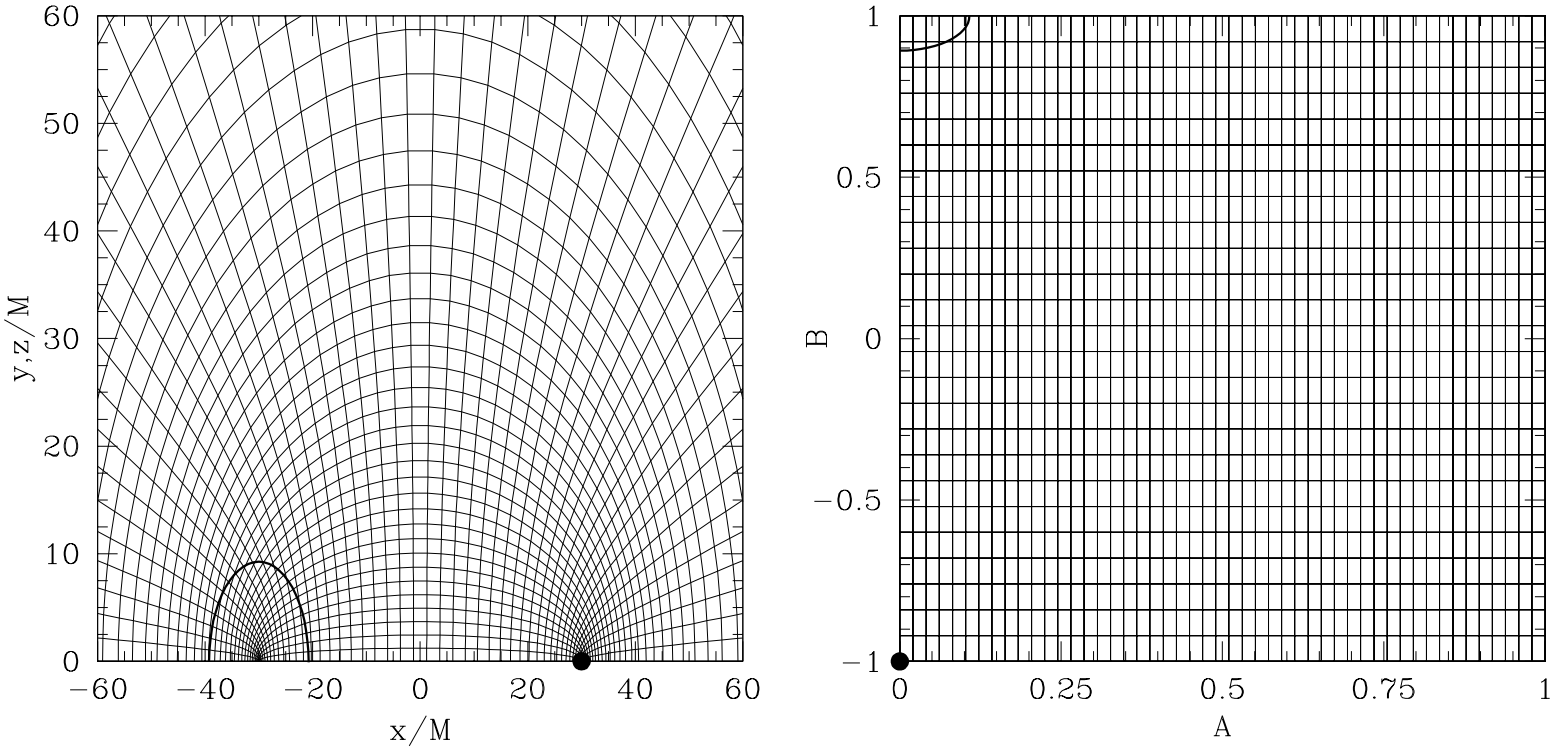
- Analog to energy and momentum conservation
- Nonlinear, elliptic equations (4)

Solver:

- spectral, compactified domain
- modified version of BBH solver by Ansorg

Recent Work - Initial data

Example for spectral grid setup:



Recent Work - Initial data

Simplification: zero (initial) velocities, time-symmetry:

- Only one elliptic equation left
- Limitation to headon collisions

Problems:

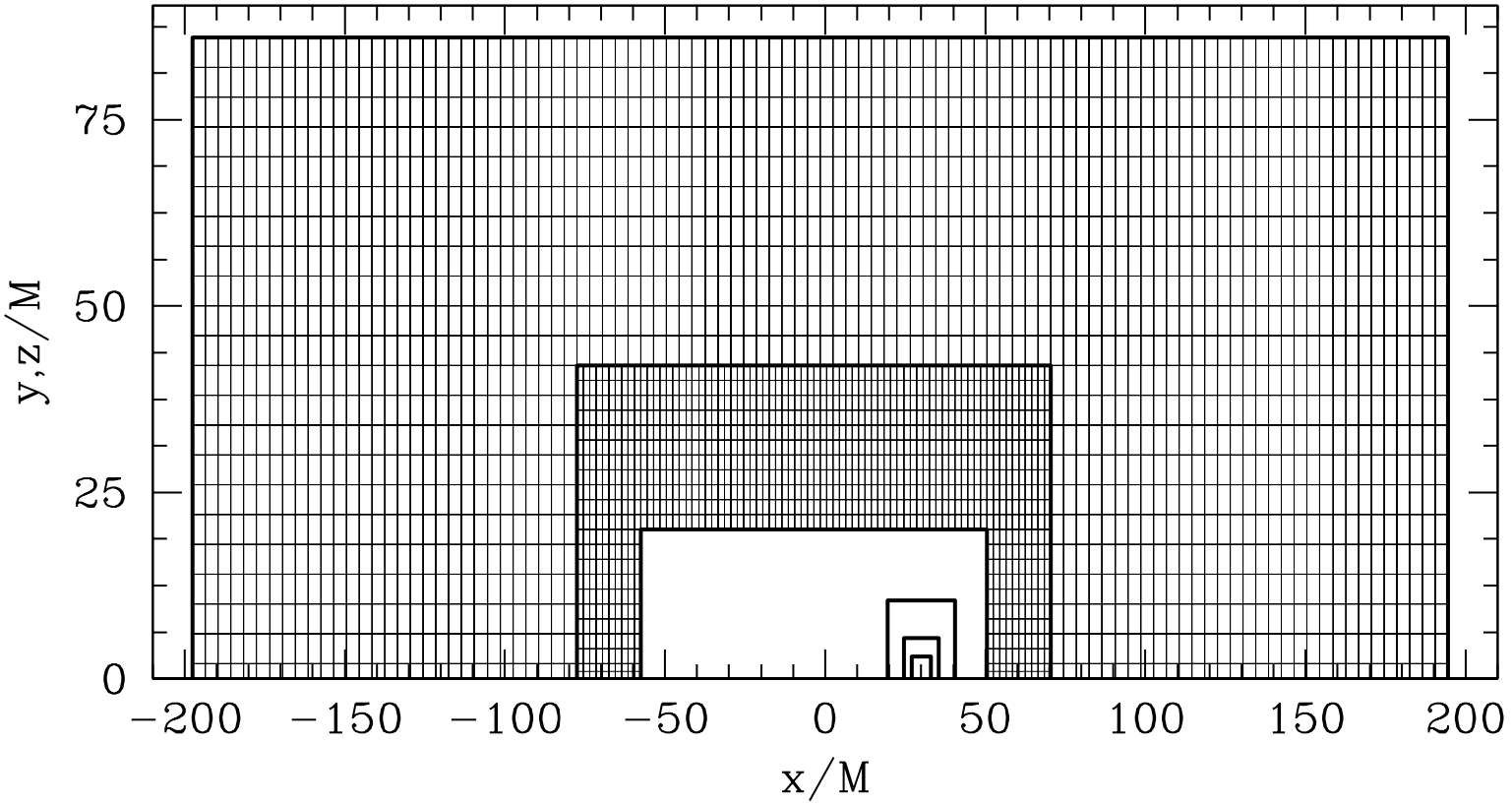
- Slow convergence (for a spectral method)
- Slow evaluation of data onto the evolution grid

Particular system:

- $M_{NS} \approx 5M_{\odot}$ (TOV, polytropic EOS)
- $M_{BH} \approx 1M_{\odot}$
- separation $d \approx 90$km

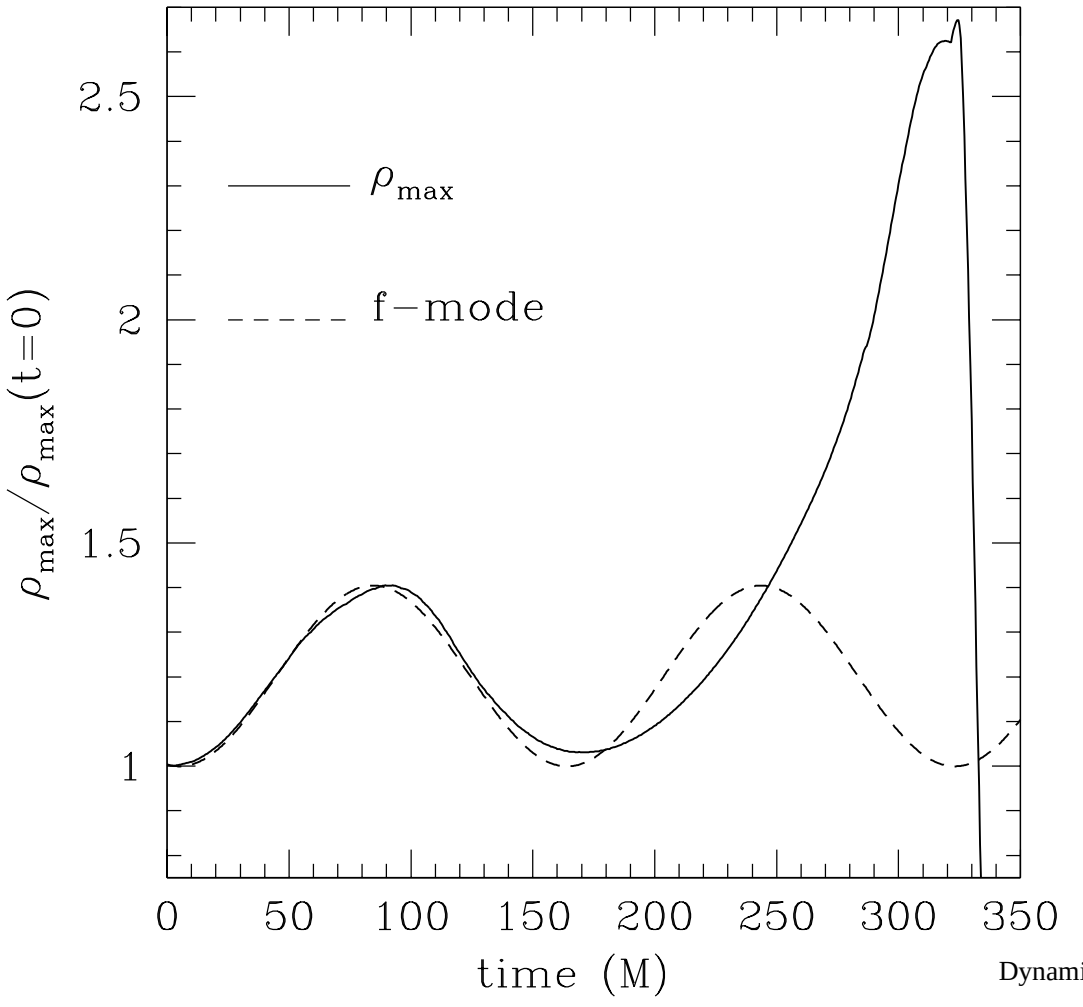
Recent Work - Evolution details

Example for evolution grid setup:



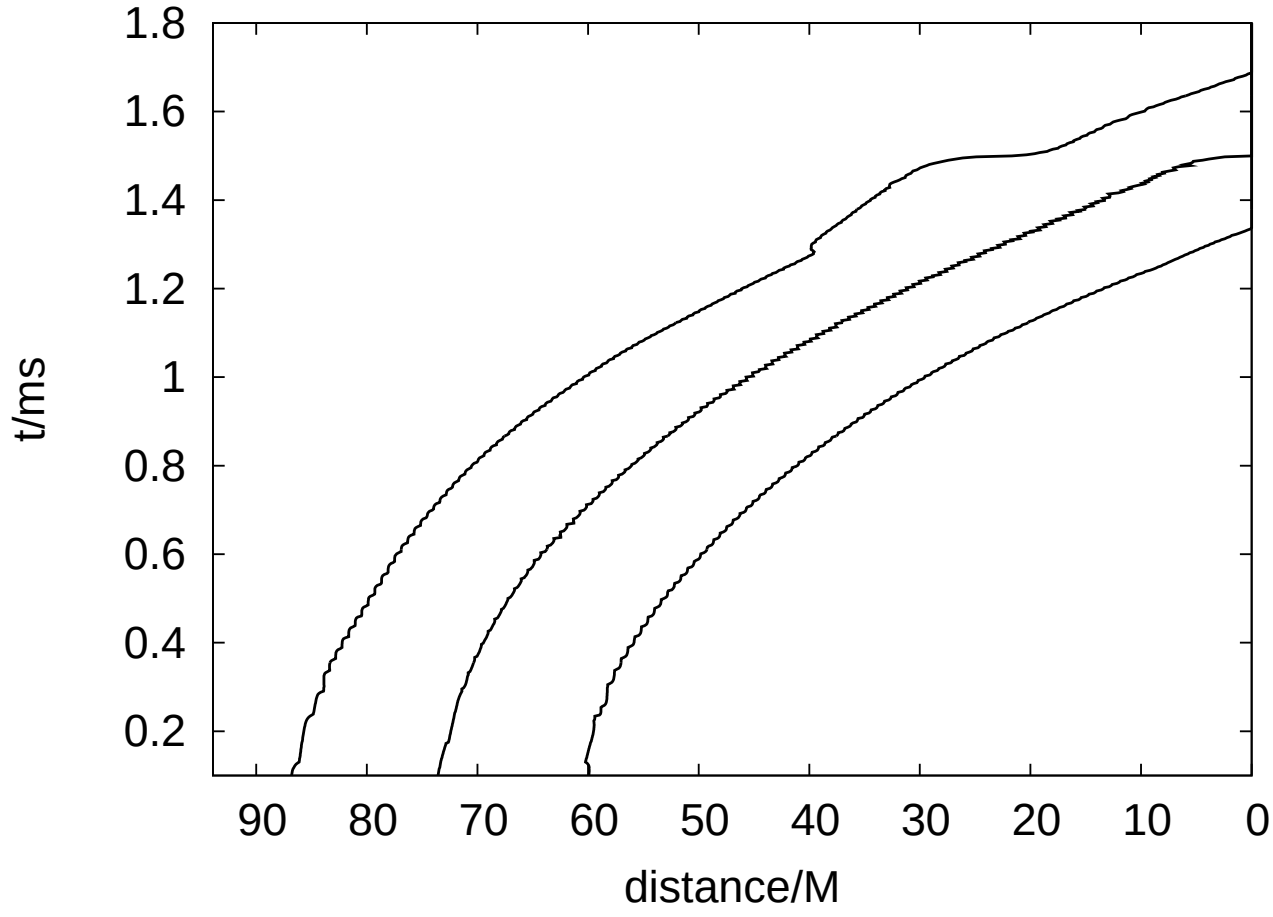
Recent Work - Evolution details

Maximum density evolution ($f_F \approx 1.28$kHz):



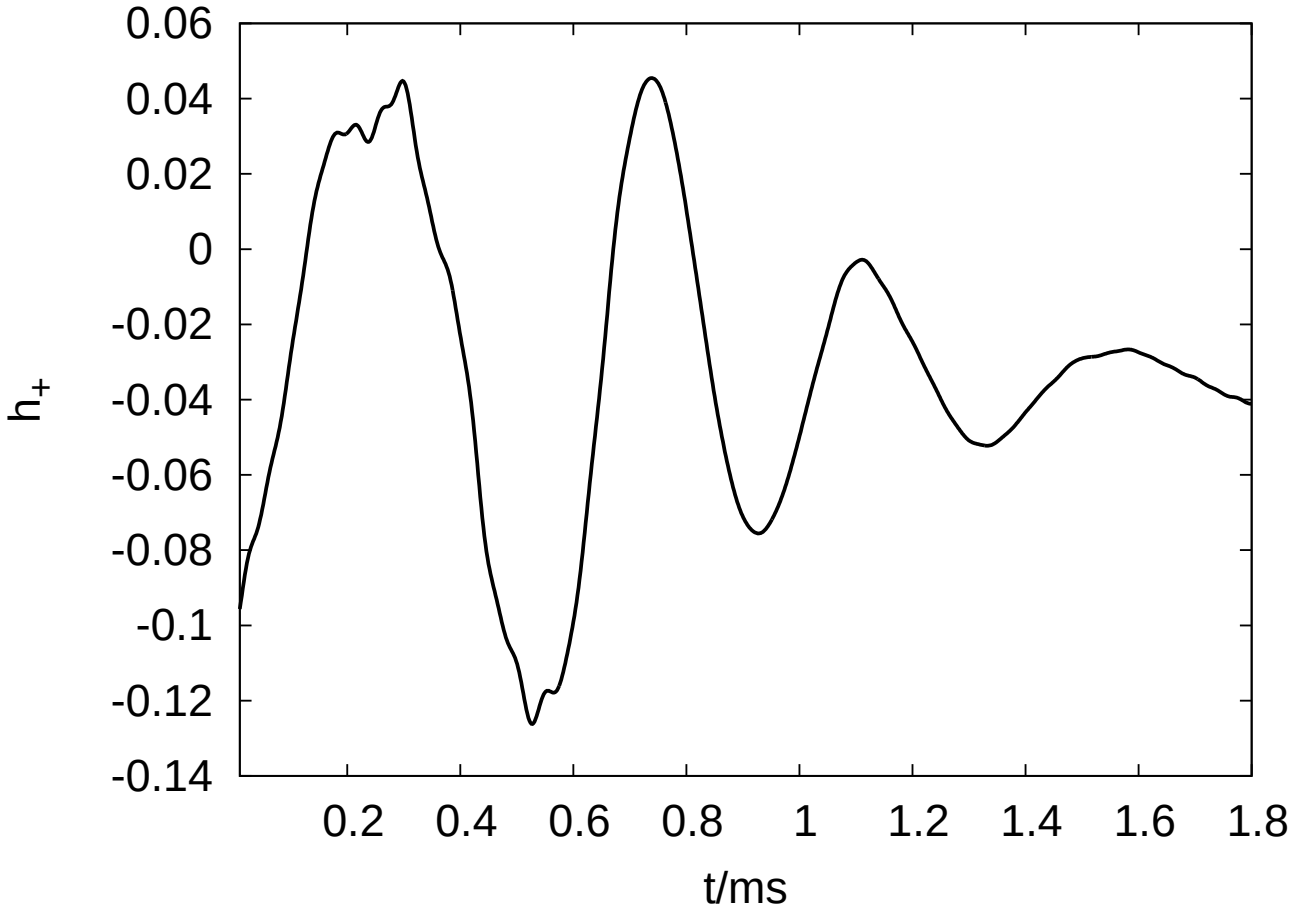
Recent Work - Evolution details

Spacetime diagram:



Recent Work - GWs

Gravitational waves ($f \approx 2.06$kHz):



Movie

Results / Future Plans

Results:

- Initial data suitable for long evolutions
- Used evolution techniques allow for long evolutions
- Gravitational waves can be obtained

Future plans:

- More realistic initial data: velocities $\neq 0$ (orbiting systems)
- Improved handling of BH interiour
- Better gauge conditions for really long term simulations
- More realistic EOS