Evolution of Binary Black Holes: A Progress Report

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GOAL:

Model a fully relativistic binary black hole merger and extract the emitted gravitational radiation.

- Important source for gravitational wave detectors
- A difficult computational challenge

OUTLINE:

- Method of Solution
- Preliminary Results
- Future Plans

LIGO-G010161-00-Z

Method of Solution:

- **Treatment of physical singularity**
  Excision
- **Formulation of the problem**
  Parameterized first-order hyperbolic system
  - mathematical analysis
  - boundary conditions
  - introduce extra variables and constraints
- **Numerical method**
  Multidomain pseudospectral method
  - high accuracy
  - analytic expression
- **Initial Data**
  Analytic, numerical
- **Gauge**
  Analytic, fixed, active
- **Boundary Conditions**
  Inner boundary: excision
  Outer boundary: freezing, constraint preserving

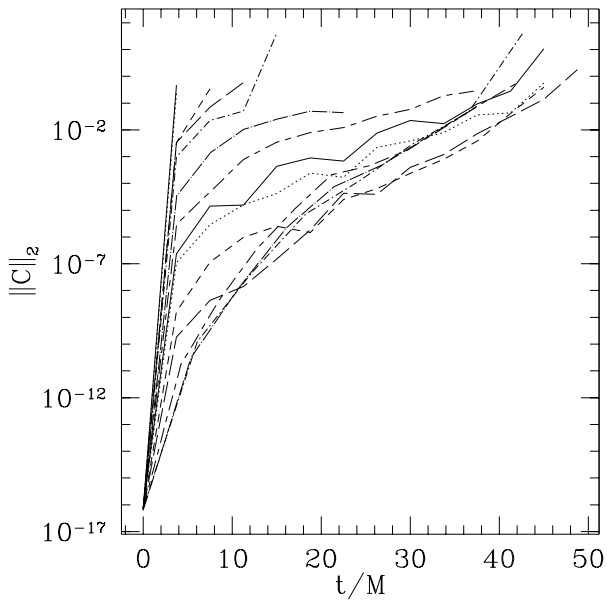
Preliminary Results:

- **Schwarschild BH, spherical symmetry (1D)**
  Einstein-Christoffel formulation [Anderson and York (1999)]
  runs forever
  exponential convergence [Kidder *et al* (2000)]
- **Full 3D evolution of Schwarschild black hole**
  evolutions quickly fail due to instabilities
  search for new formulation of evolution equations
  constructed a parameterized hyperbolic system
  - cast into first-order form
  - modify evolution equations by adding constraints and redefining variables
  - numerical parameter search
  - stability depends upon choice of parameters
  - evolution runs long enough

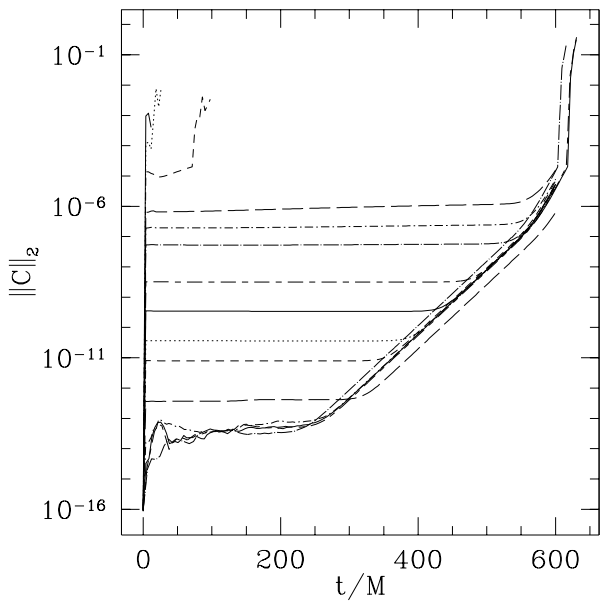
  [Kidder, Scheel, and Teukolsky (2001)]
- **Binary black holes evolutions**
  start with holes well separated
  thin sandwich initial data
  experiment with quasi-equilibrium BCs
  study gauge conditions

Parmaterized Hyperbolic System:

$\bar{z} = 0, \eta = 4$



$\bar{z} = 1, \eta \sim 1/8$



- Spherical shell: $r/M = [1.9, 11.9]$
- PG slicing, analytic gauge
- resolution ($N_r = 8 - 48, N_\theta = 8, N_\phi = 15$)

Future Plans:

- **Formulation of the problem**
  Expand parameter search
  Look for theoretical guidance
  Conformal decomposition
- **Numerical method**
  Compare with finite difference methods
  Improve domain decomposition
- **Initial Data**
  Which initial data is best?
- **Gauge**
  Horizon locking?
  What else?
- **Boundary Conditions**
  Constraint preserving
  What to do with free modes?
- **Diagnostics**
  How do you characterize a solution?
  Constraints, apparent horizons
  Wave extraction