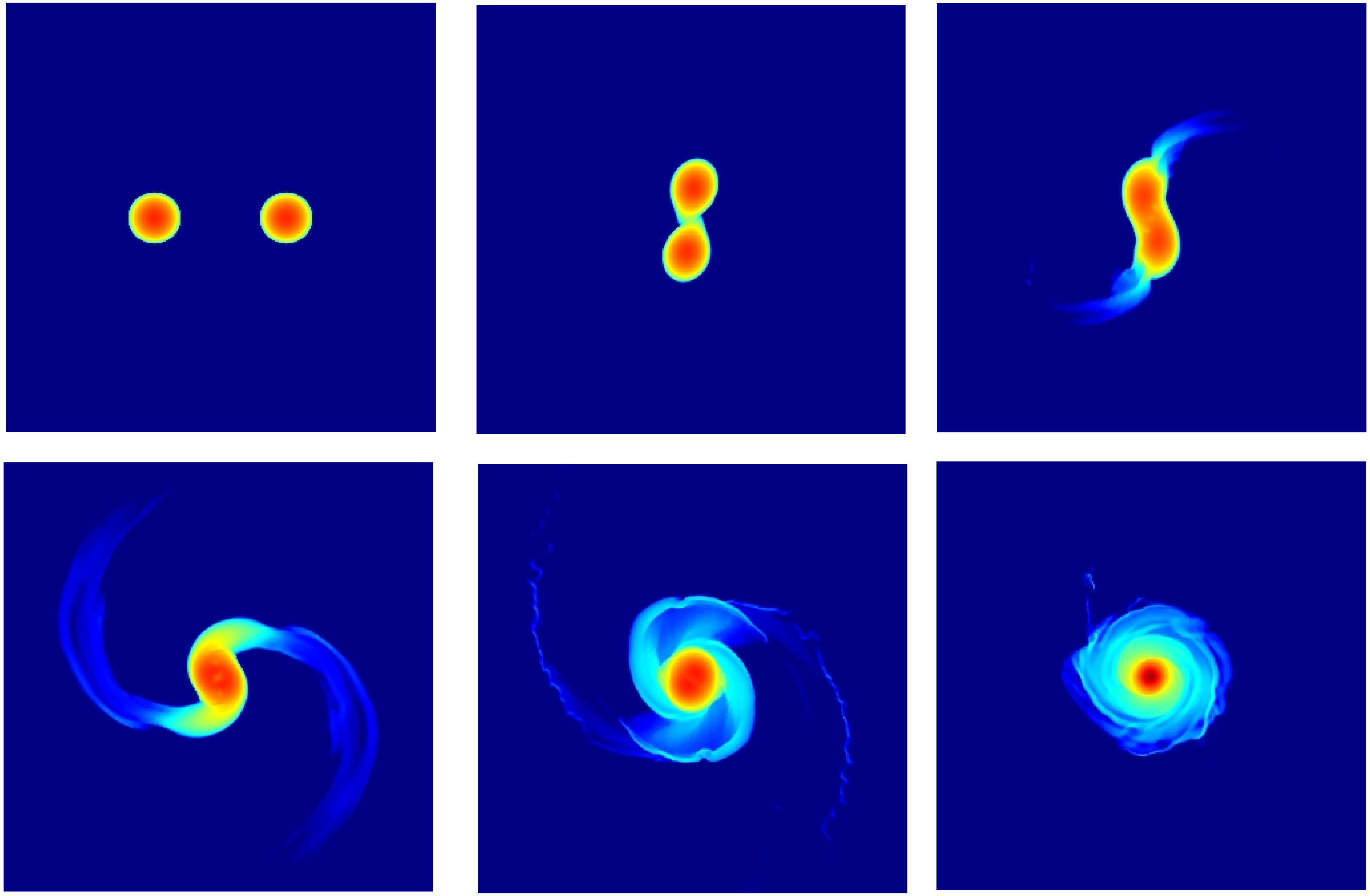
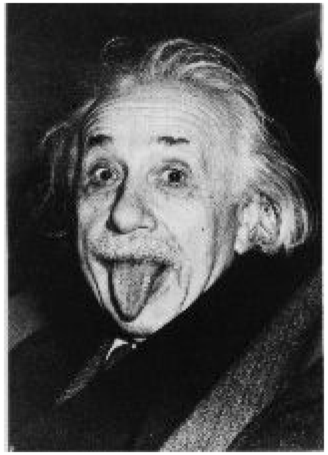
General Relativistic Decompression of Binary Neutron Stars During Inspiral

Mark Miller
Mark.A.Miller@jpl.nasa.gov
Jet Propulsion Laboratory





Numerical Relativity: Solving the Einstein field equations, which govern gravitational phenomena, on supercomputers.

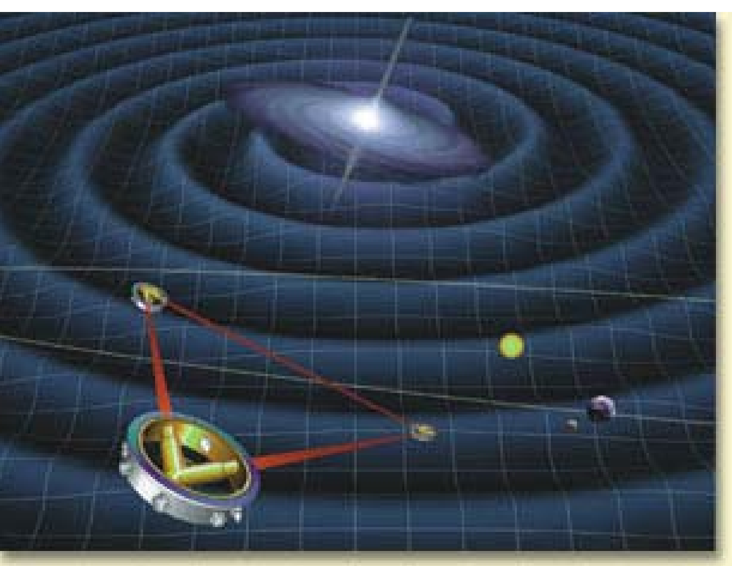
- The Einstein field equations are arguably the most complicated set of nonlinear partial differential equations in all of classical physics!
- If written out in full generality (which is the case we solve on computers), the equations would take tens of pages.
- Black holes are particularly nasty to treat numerically, since they contain physical singularities.
- Gravitational waves given off by neutron stars and black holes have wavelengths hundreds of times larger than the length scale of the objects themselves: this is difficult to treat numerically.
- Realistic simulations often take hundereds of thousands of hours of CPU time or more!

Q: Why would one want to solve the Einstein field equations in the first place?

A: If we knew what kind of gravitational wave signals were produced by coalescing black holes and neutron stars, we could turn gravitational wave detection into a seperate branch of astronomy: ***Gravitational Wave Astronomy***!

LISA: Laser Interferometer Space Antenna

http://lisa.jpl.nasa.gov



LIGO: Laser Interferometer Gravitational Wave Observatory

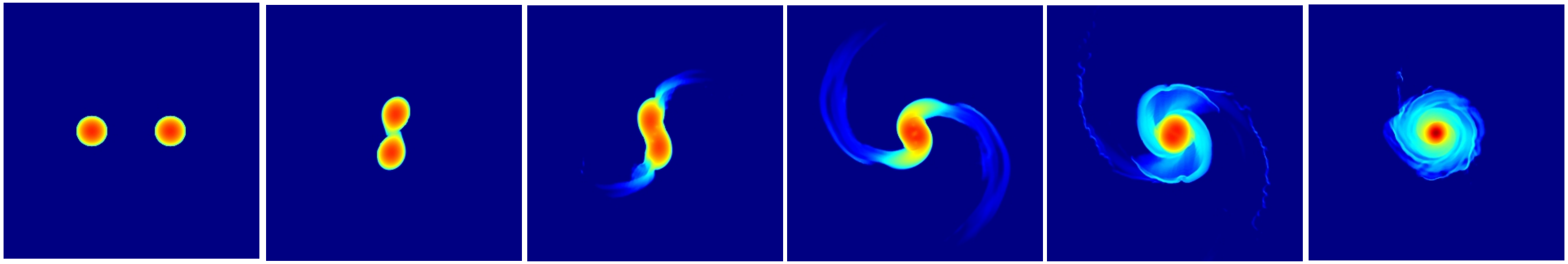
http://www.ligo.caltech.edu

Hanford, Washington site

Do the mutual tidal forces of binary neutron stars cause them to collapse (to black holes) before merger?

"General Relativistic Decompression of Binary Neutron Stars During Inspiral" - MM gr-qc/0510020

- **general relativistic hydrodynamics simulations:** 2nd order finite difference discretization, BSSN formulation for Einstein equations, HRSC methods for hydro, local gauge conditions, Sommerfeld-like boundary conditions for GR fields, outflow boundary conditions for hydro
- **initial data:** circular orbit, quasi-equilibrium, conformally flat, corotating



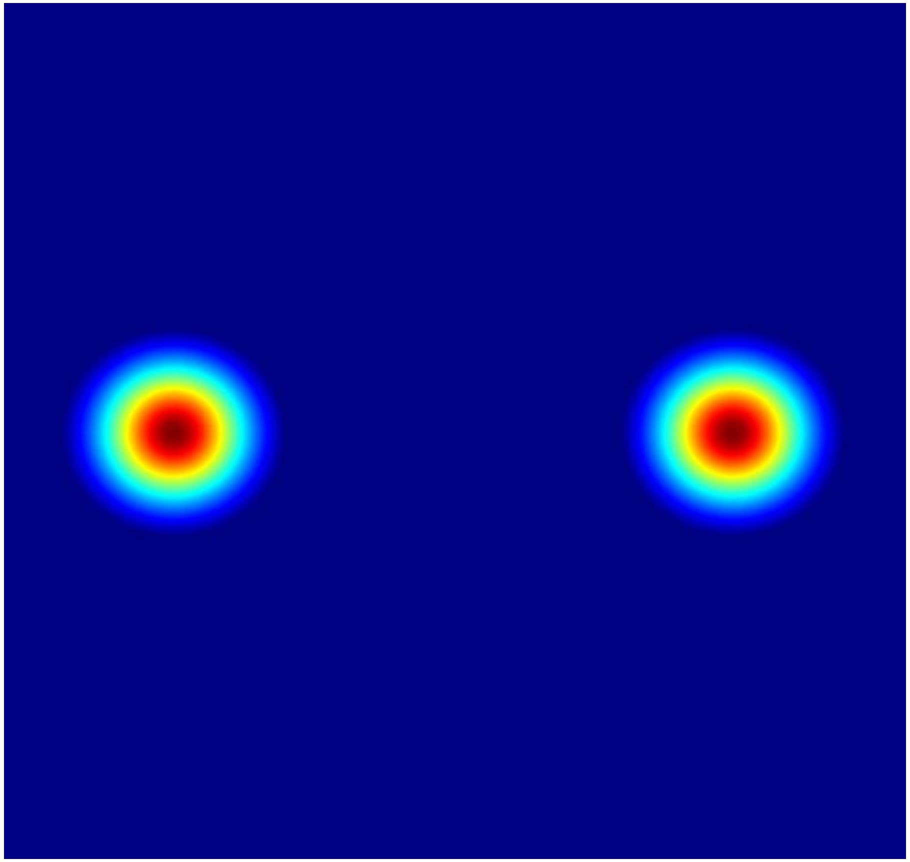
Idea: track multiple-orbit simulations to look for "precompression" effect (as reported in Mathews and Wilson - Phys. Rev. D 61 (2000); Wilson - Phys Rev. D 66 (2002); Wilson and Mathews - ApJ 610 (2004); Dearborn, Wilson, Mathews – ApJ 630 (2005)).

Evidence to the contrary: Lai – Phys. Rev. Lett 76 (1996); Wiseman – Phys. Rev. Lett 79 (1997); Brady and Hughes – Phys. Rev. Lett. 79 (1997); Baumgarte, Cook, Scheel, Shapiro, Teukolsky – Phys Rev. D (1997); Flanagan - Phys. Rev. D 58 (1998); Thorne – Phys. Rev. D 58 (1998); Taniguchi and Gourgoulhon – Phys. Rev. D 66 (2002) and Phys. Rev. D 68 (2003).

Perform fully general relativistic calculation to answer this question.

Initial Data:

• Neutron stars: circular orbit, quasi-equilibrium, co-rotating
• decrease angular velocity by 2 -4%, and resolve Hamiltonian and momentum constraints: eccentric orbit



Evolution:

• HRSC hydro methods, BSSN spacetime, "1+log" lapse evolution, gamma-driving shift
•perform large scale computations: ~10,000 timesteps, ~700^3 gridpoints, 1/2 Terabyte of memory

Orbital separation (r) and central density (ρ_{center}) of Neutron Stars

(Initial Data: quasi-equilibrium with 3% angular velocity reduction)