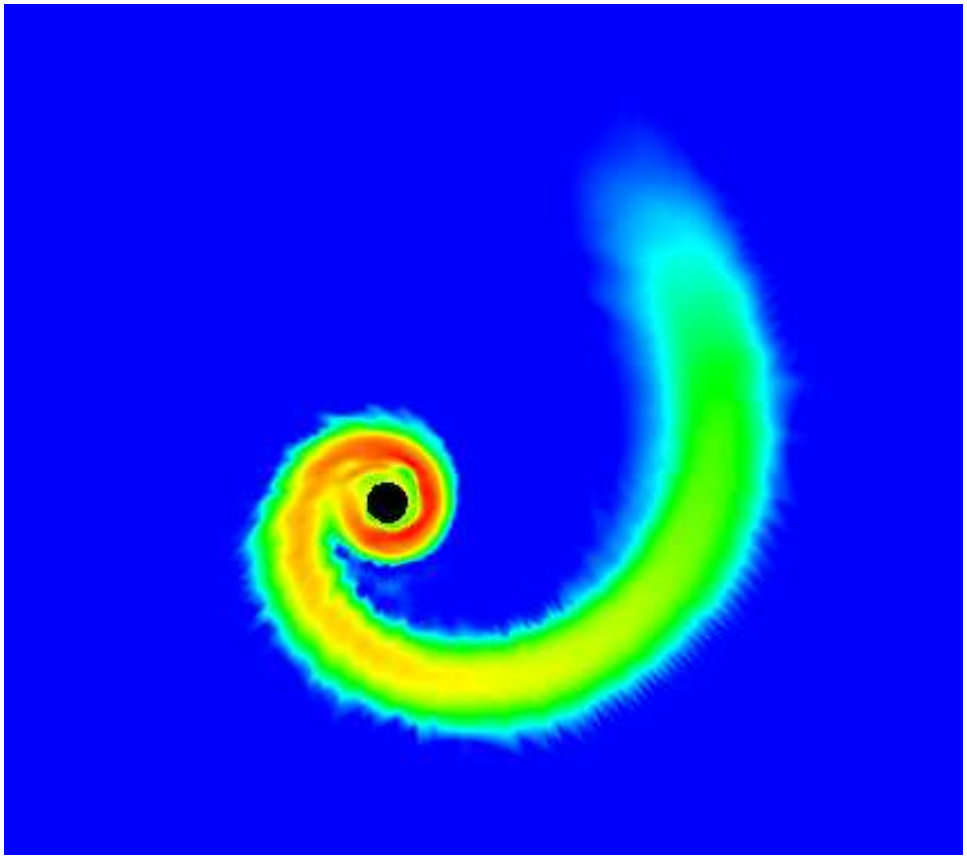
Simulations of Spinning Black hole-neutron star mergers

Matthew Duez, Francois Foucart,
Larry Kidder, Saul Teukolsky



RIT, June 15, 2008

Black hole-neutron star binaries

Importance

- gravity waves
- GRB (disk)
- r-process generator (outflow)
- equation of state (EoS) info

Parameters

- $M_{\rm BH}$, $M_{\rm NS}$ ($\rightarrow R_{\rm NS}$)
- $\vec{J}_{\rm NS}$ (small), $\vec{J}_{\rm BH}$ ($\rightarrow r_{\rm ISCO}$)

Degrees of Realism

- gravity: Newtonian vs conformal vs GR
- EoS: polytrope vs nuclear theory

  $P(\rho)$ vs $P(\rho, T, Y_e)$
- other physics: $\vec{B}$, L_ν, etc

Our Code

- **GR:**
  Generalized harmonic formulation
  Fixed H_μ or exp. decay
  Evolve in comoving frame
  multidomain pseudospectral (PS) evolution

- **Hydro:**
  perfect fluid: $P = (\Gamma - 1)\rho\epsilon$
  finite volume, PPM, HLL
  Cartesian fluid grid

- black hole excision
- grids communicate by interpolation
- map relating PS to fluid coordinates

Improvements to our code

- automated remapping of fluid grid to track matter

- fix H_μ on excision surface during merger
  exponential decay of H_μ far from hole

- improved atmosphere control
  - ◇ limit u_i rather than v^i
  - ◇ for non-polytropes, limit h rather than κ
  - ◇ limit $g^{ij}S_iS_j < [1 - f(\rho)]\tau(\tau + 2D)$
    –adjust S_i or τ, depending on τ
  - ◇ tidal tail is sensitive to $f(\rho)$–must be <u>small</u>

- $|\mathcal{C}|_{\text{max}} \sim 10^{-2}$ (factor of 10 improvement)

Spinning holes–UIUC results

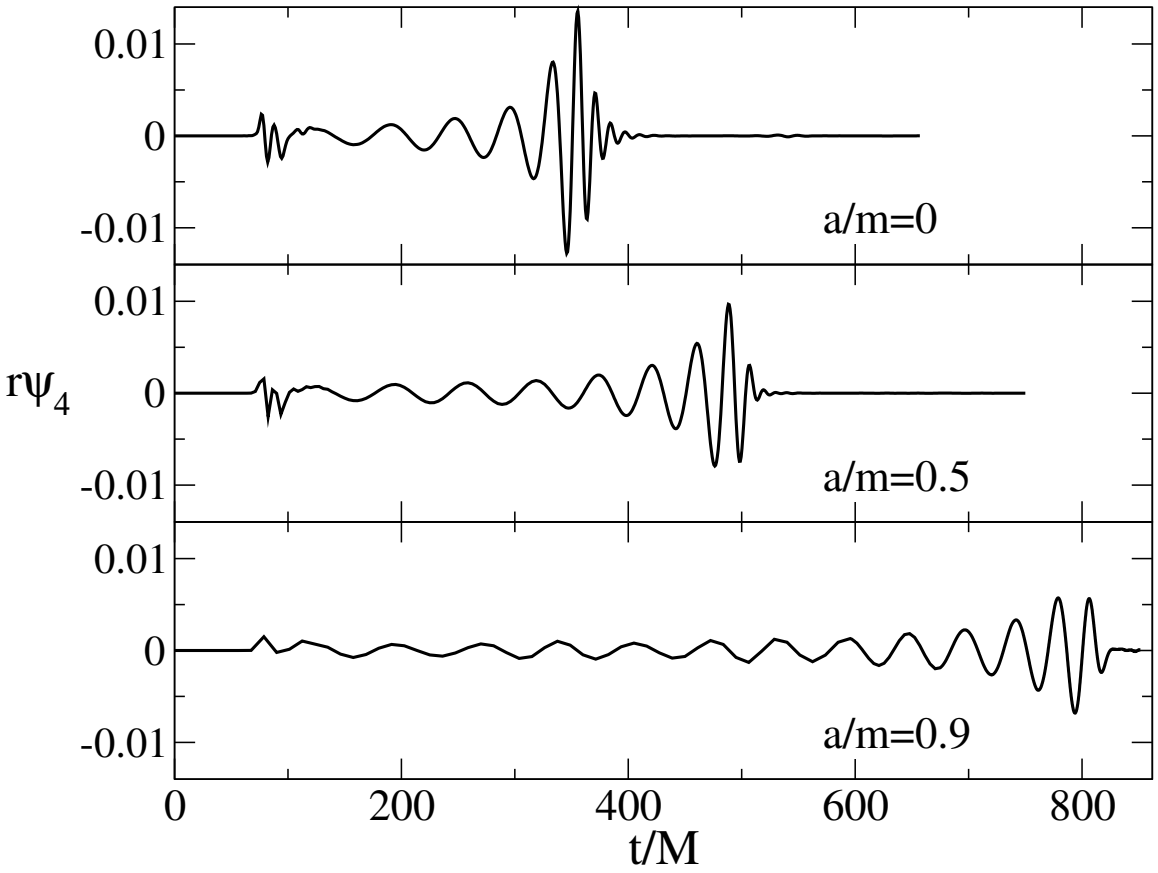
- Etienne, Liu, Shapiro, and Baumgarte (2009)
- $M_{\rm NS}/R_{\rm NS} = 0.145$, $M_{BH}/M_{NS} = 3$, $\Gamma = 2$
- $s_{\rm BH} \equiv J_{\rm BH}/{M_{\rm BH}}^2 =$ -0.5, 0, 0.75 (aligned)
- orbital hang-up:
  inspiral lasts 3.25, 4.5, 6.5 orbits
- $M_{\rm disk} =$ $<$1%, 4%, 15% of $M_{\rm NS}$
- $T_{\rm disk} \approx$4MeV

Our cases

- $M_{\rm NS}/R_{\rm NS} = 0.15$, $M_{BH}/M_{NS} = 3$, $\Gamma = 2$
- $d_{\rm sep,init}$/M=7.5
- $s_{\rm BH}$ = 0, 0.5, 0.9 (aligned)
- inspiral: 5000SU on 32 procs
- merger: 10000SU on 40 or 48 procs

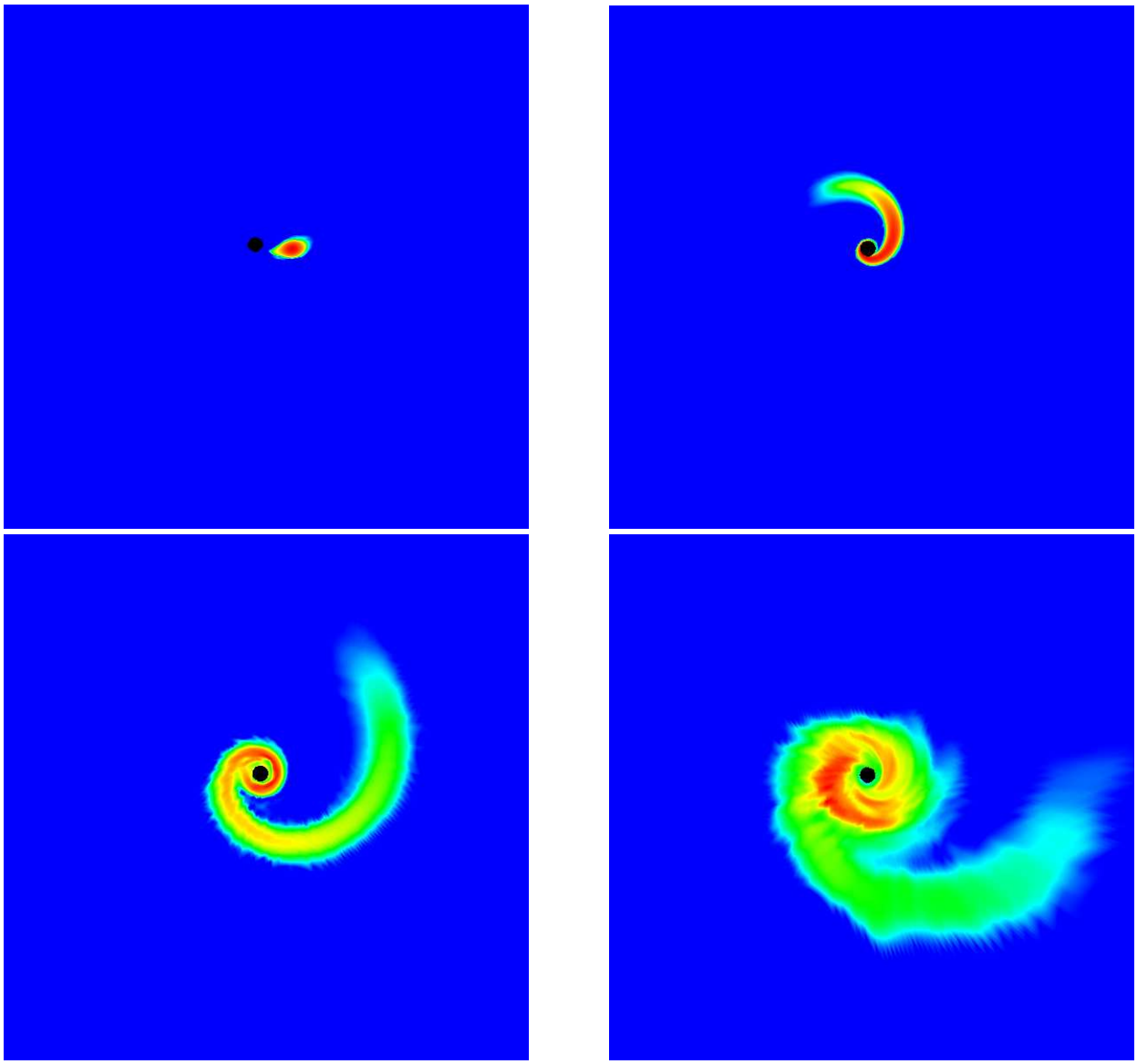
Results: Orbital hang-up & waveform

- inspiral lasts 1.9, 2.7, 5.2 orbits

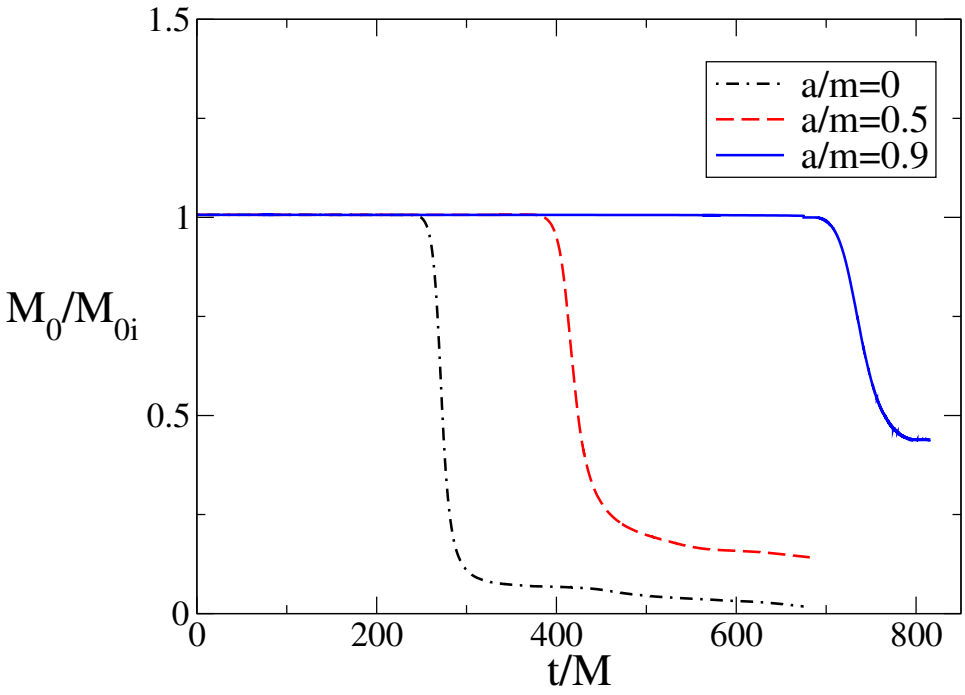


- $s^{\text{final}}_{\text{BH}} =$ 0.56, 0.78, 0.93

NS destruction: general features



Results: accretion disks



- $M_{\rm disk} =$ 1%, 10%, 40% of $M_{\rm NS}$
- $T_{\rm disk} =$ 2, 2, 6 MeV
- $r_{\rm disk} \sim$ $20M$
- $\rho_{\rm disk} \sim$ 10^{12}, 10^{13}, 10^{14} g cm^{-3}

Conclusions

- code improvements vastly improved accuracy
- large amount of matter outside hole
  10ms after merger
- strong dependence on BH spin
- qualitative agreement with UIUC