

*Status of LSU-BYU-LIU
collaboration on binary systems*

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Outline

- Addressing possible systematics in gravitational wave extraction.
- Binary black hole examples
- Binary neutron stars
- Binary boson stars

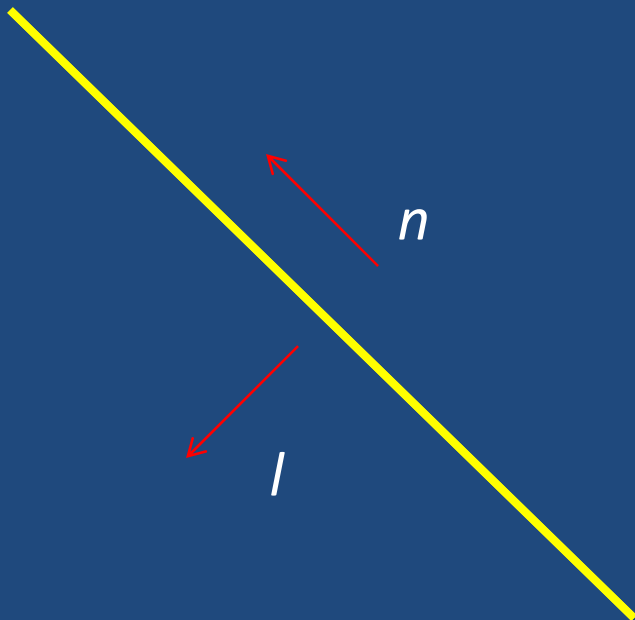
Extraction of waves

Two techniques.... Both cavalier so far

Perturbative approach (Zerilli, Teukolsky) requires singling out a background.

Weyl scalars. Assumes asymptotic structure holds at finite distances, ignores gauge issues.

Weyl scalars



$$\Psi_4 = C_{abcd} n^a \bar{m}^b n^c \bar{m}^d$$

$$\Psi_2 = C_{abcd} l^a m^b \bar{m}^c n^d$$

$$\sigma = m^a m^b \nabla_a l_b$$

$$\Psi_4^0 = -\bar{\sigma}_{,uu}$$

$$M = \frac{1}{4\pi} \int (\Psi_2 + \bar{\sigma}_{,u} \sigma) d\Omega$$

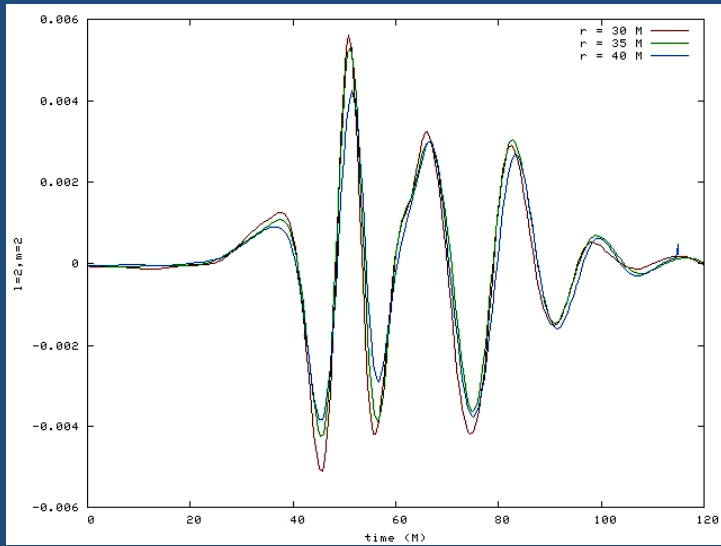
$$\dot{M} = -\frac{1}{4\pi} \int \bar{\sigma}_{,u} \sigma_{,u} d\Omega$$

- What's the deal in numerical relativity?
 - Tetrad (l, n, m, m^*) is defined at a finite distance. $X^2 = R^2$
 - *Background metric?*
 - Induced angular metric $g = S + C/r$ with S the unit sphere metric
 - *Angular part only conformal to unit sphere metric $S = q V^{-2}$*
 - $g_{uu} = 1; g_{uA} = 0$ (inertial observers stay at const angles; clocks tick the same)

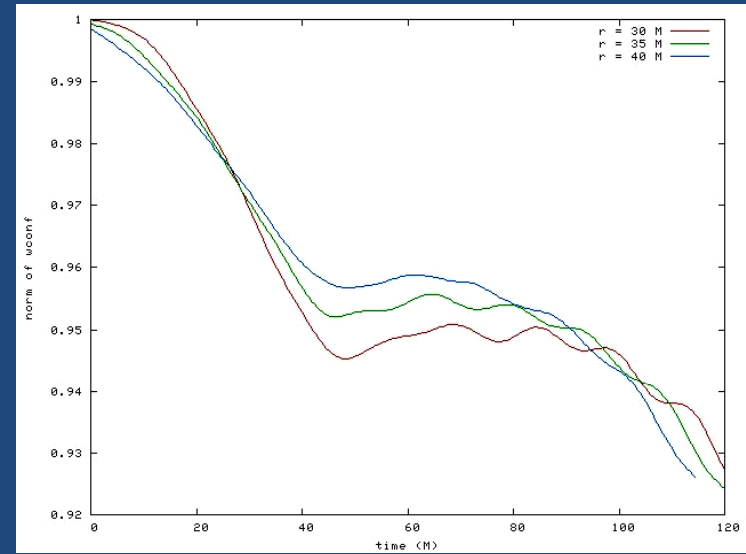
Corrections?

- simplest case ($g_{uA} = 0$)

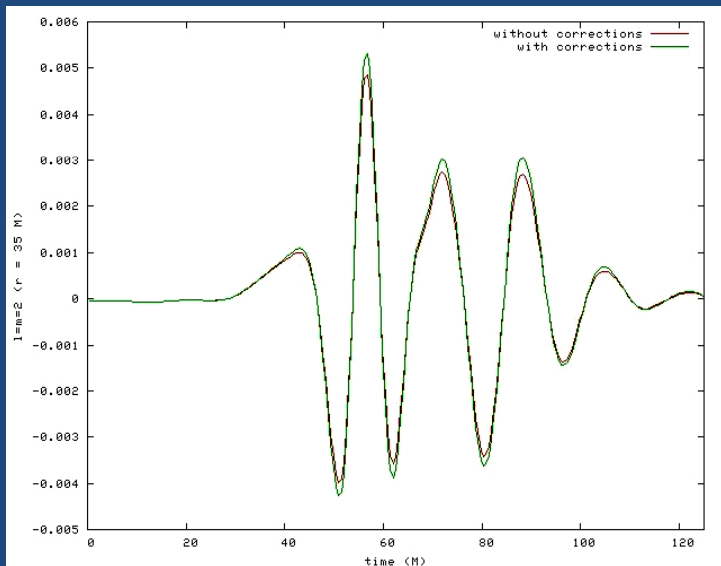
$$\Psi_4 = \mathcal{I}_4 / (V^3 g_{ur}^2)$$



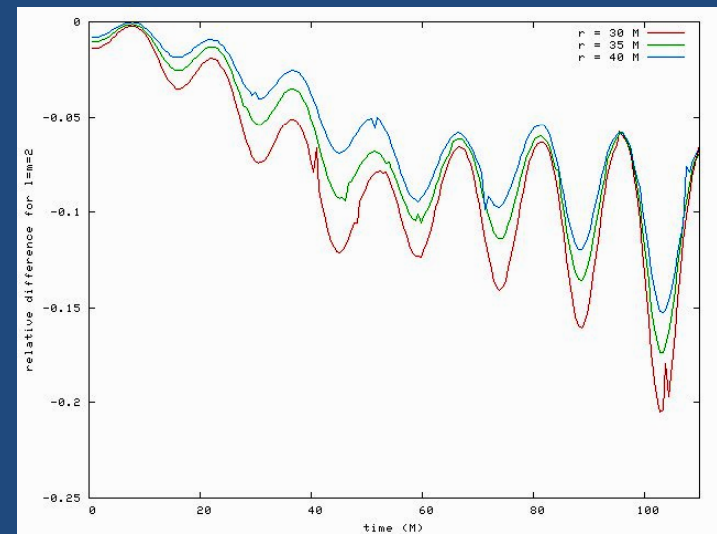
Uncorrected waveforms



Conformal factor.. Not = 1!



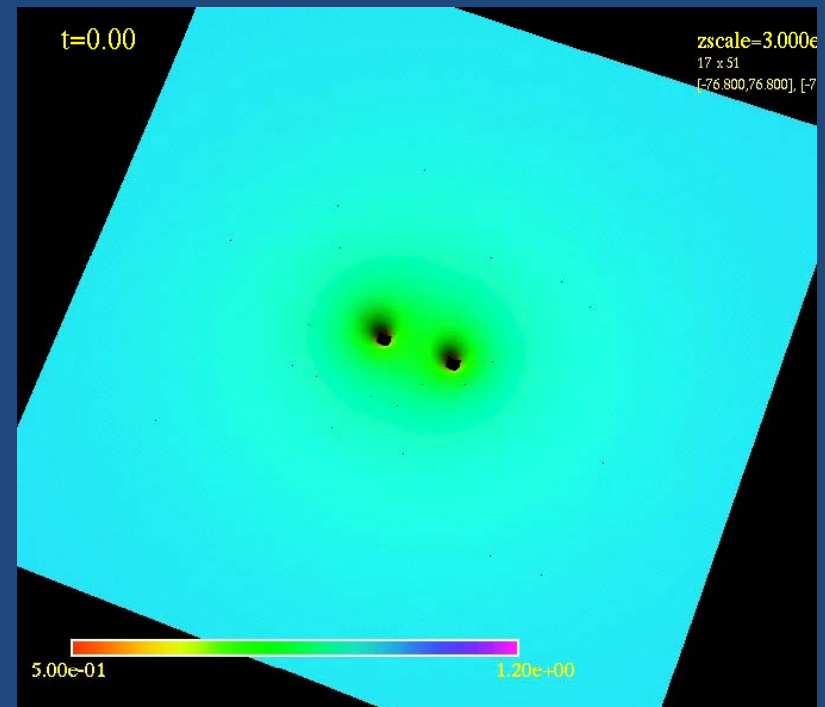
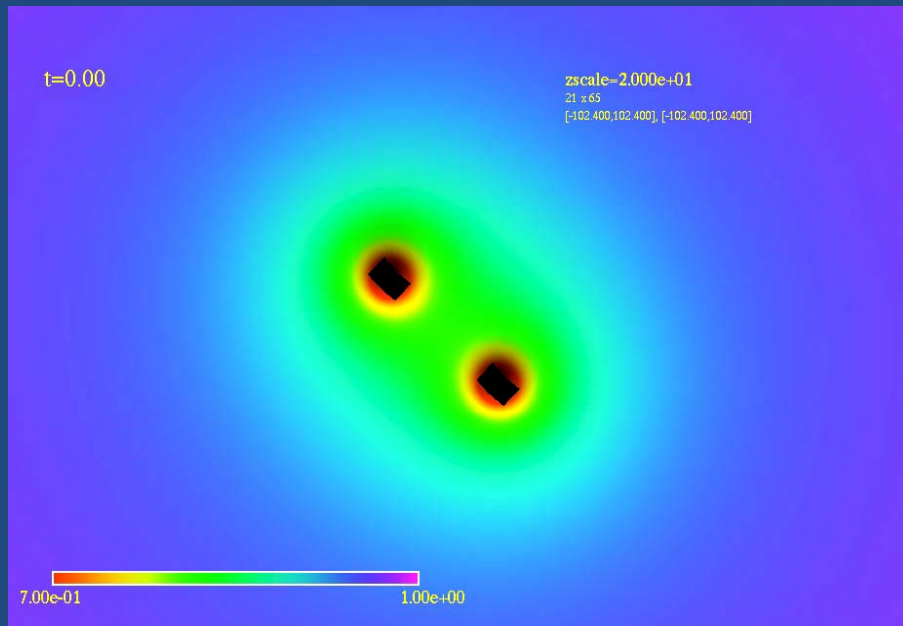
Corrected/uncorrected waveforms



Differences between corr/uncorr not $\rightarrow 0$

ID and dynamics

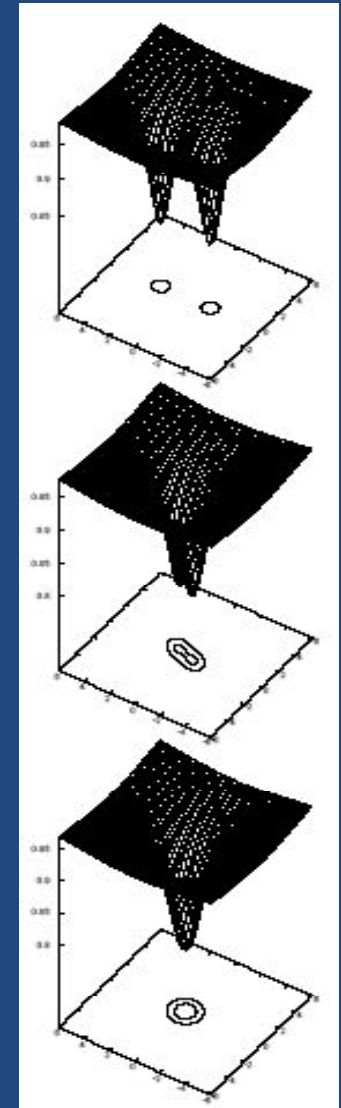
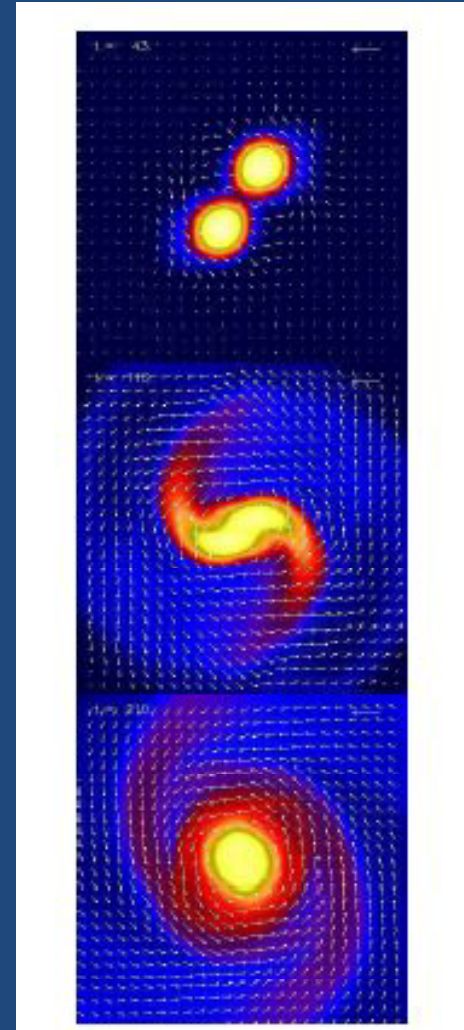
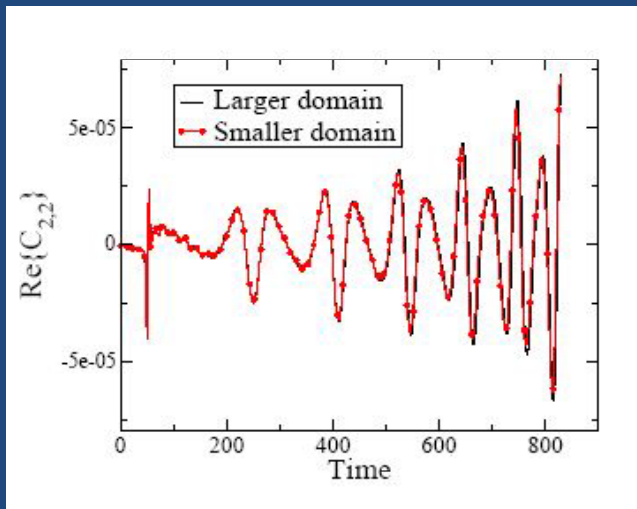
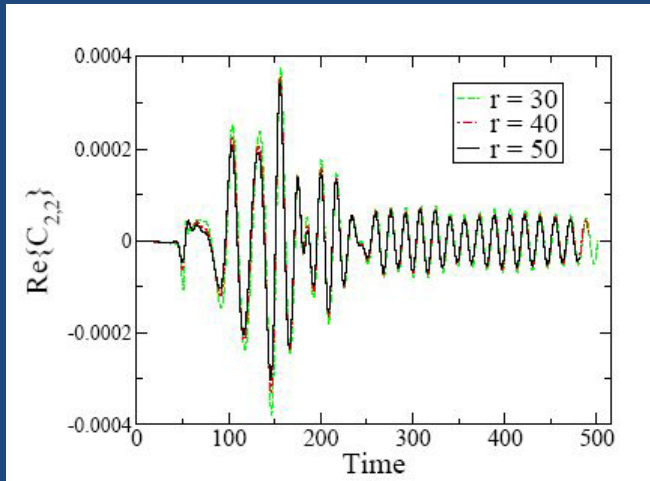
- Boosted KS (no punctures), not as easy related to PN



[Anderson, Hirschmann, LL, Liebling, Motl, Neilsen, Palenzuela, Tohline]

Waveforms & simplicity?

Early times \sim PN, merger knows about internal structure



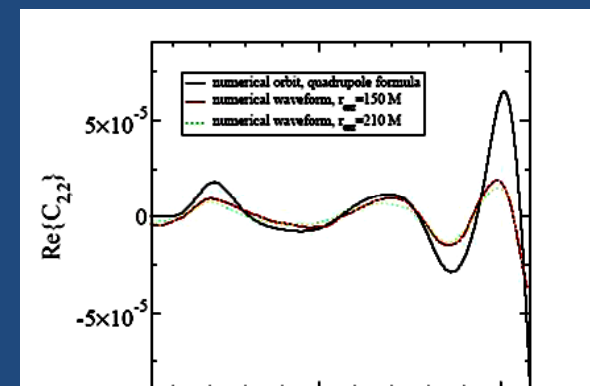
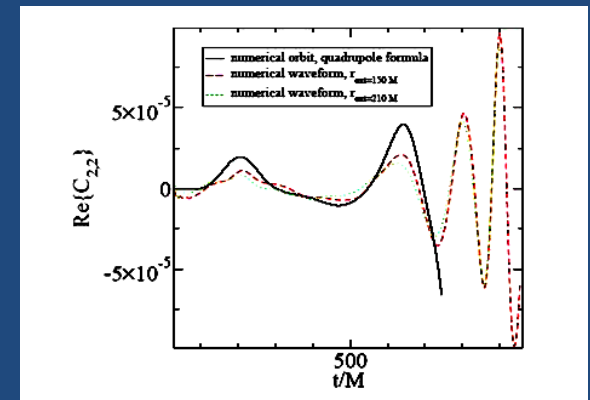
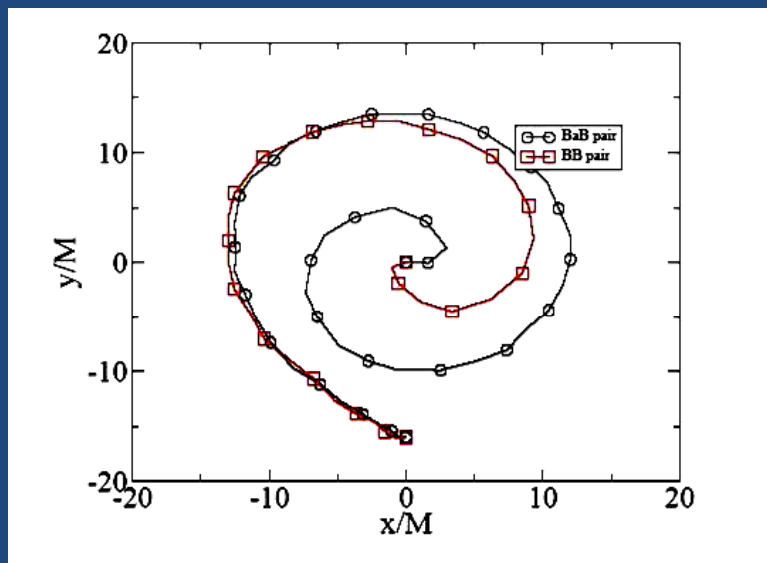
[Anderson,Hirschmann,LL,Liebling,Motl,Neilsen,Palenzuela,Tohline]

Binary and dynamical B Boson Stars

more differences due to internal structure, though early \sim PN

3 cases of 'interaction term':

- $\square \quad \triangle$ (boson – boson; $\kappa = 0$)
- $\square - \triangle$ (boson – PO boson; $\kappa = \pi$)
- $\square \quad \triangle \cos(2\omega t)$ (boson – antiboson*; $\kappa = 0$)



[Palenzuela, L.L., Liebling 07]

Situations & degeneracies

- Simple model to estimate spin (isco...,etc)
[Buonanno,Kidder,LL]
 - Basic phenomenology can be understood by simple Newtonian+Perturbation arguments.
 - Worry, untangling degeneracies will be very difficult, if $S_1+S_2=0$... waves will be 'almost' identical...