Title: How much longer? Length requirements for numerical-relativity waveforms

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Abstract: TBA

How much longer? Length requirements for numerical-relativity waveforms

Mark Hannam
University of Vienna

In collaboration with
P. Ajith, S. Husa, D. Müller, F. Ohme, B. Brügmann

NR-DA Meeting
Perimeter Institute, June 24, 2010

Part I

What we've been doing

How much longer? Length requirements for numerical-relativity waveforms

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Part I

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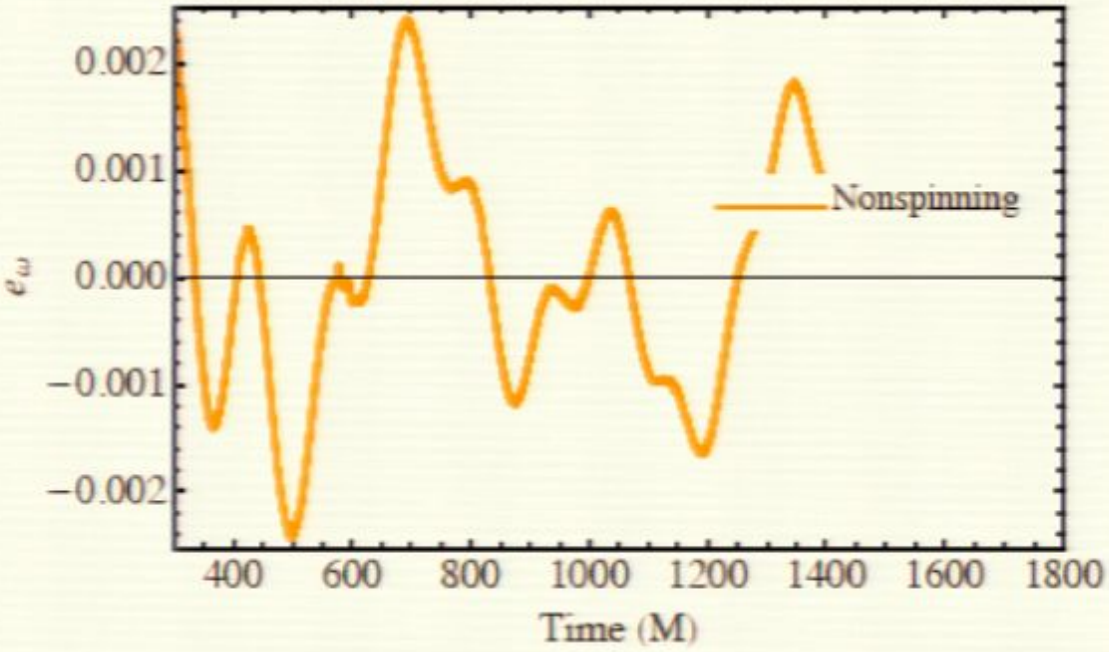
Non-precessing-spin waveforms

12 different cases

Mass ratios $q \in [1, 4]$

Non-precessing spins $|\chi_i| \in [0, 0.85]$

Low-eccentricity inspiral



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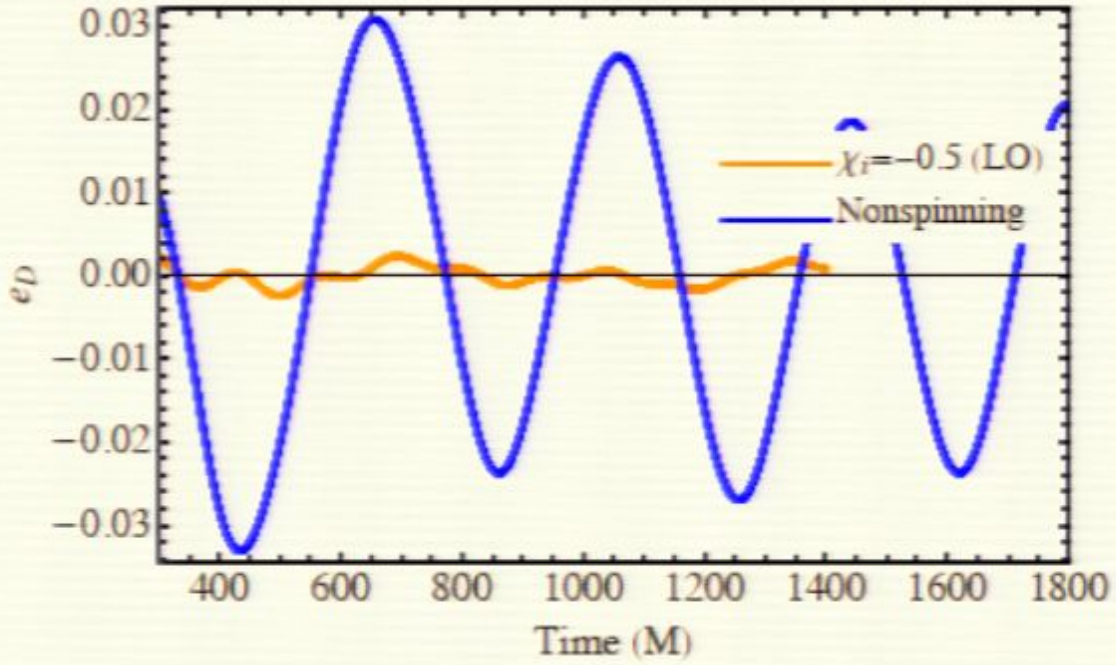
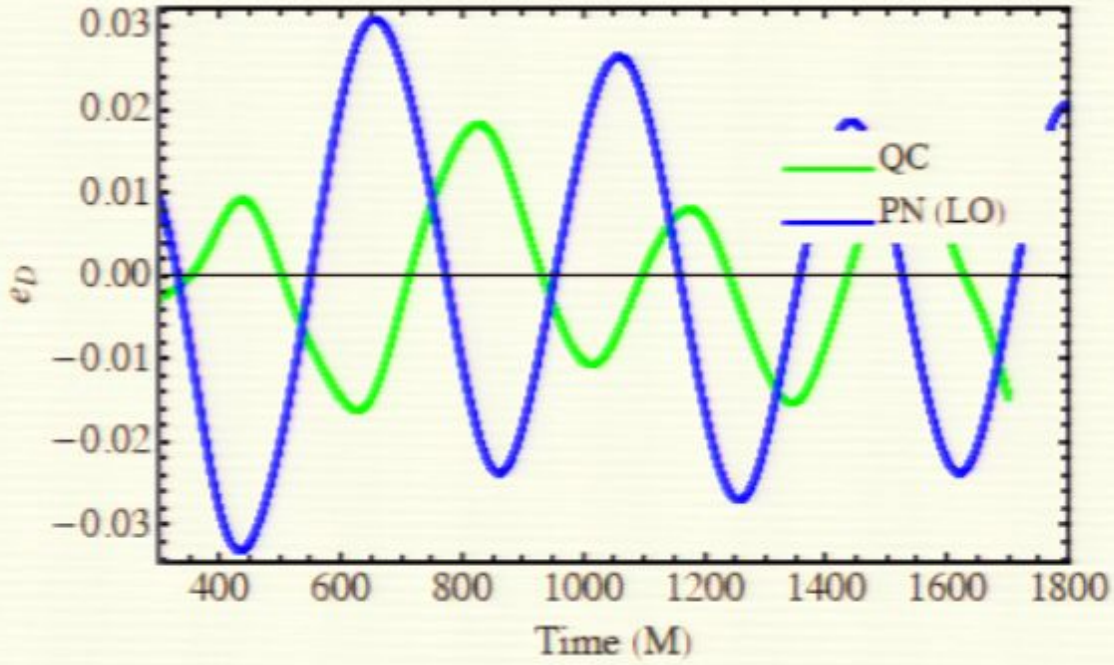


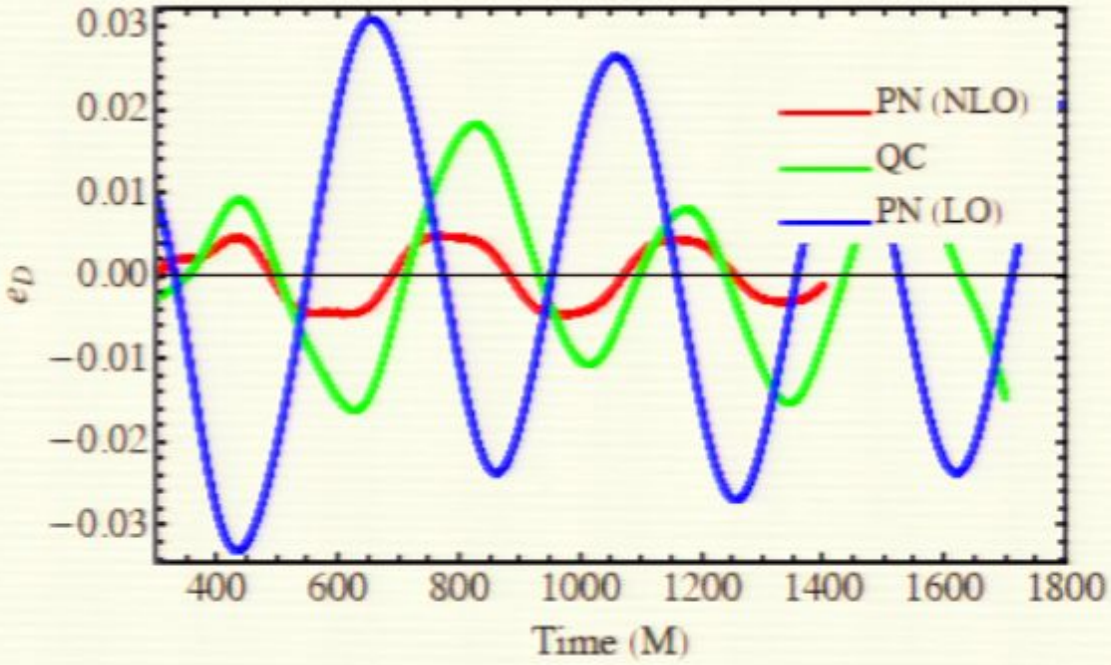
Parameters	p_x	$p_y\,(\times 10^{-4})$	e
PN (LO)	0.0861204	−5.8243	0.03

Low-eccentricity inspiral



Parameters	p_x	$p_y(\times 10^{-4})$	e
PN (LO)	0.0861204	-5.8243	0.03
QC	0.0846891	0	0.015

Low-eccentricity inspiral



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PN (LO)	0.0861204	−5.8243	0.03
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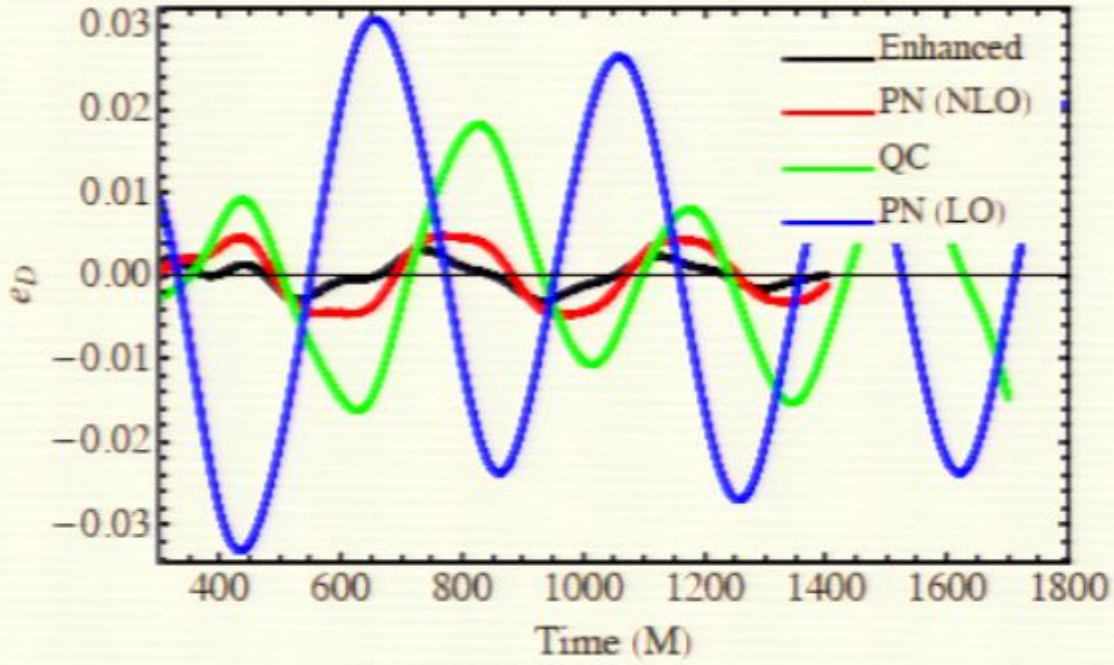

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PN (LO)	0.0861204	−5.8243	0.03
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Enhanced	0.0851238946	−5.257824925	0.003

Toward higher mass ratio simulations

$\tilde{\Gamma}$–driver condition

$$\partial_0^2 \beta^i = \frac{3}{4} \partial_0 \tilde{\Gamma}^i - \eta \partial_0 \beta^i$$

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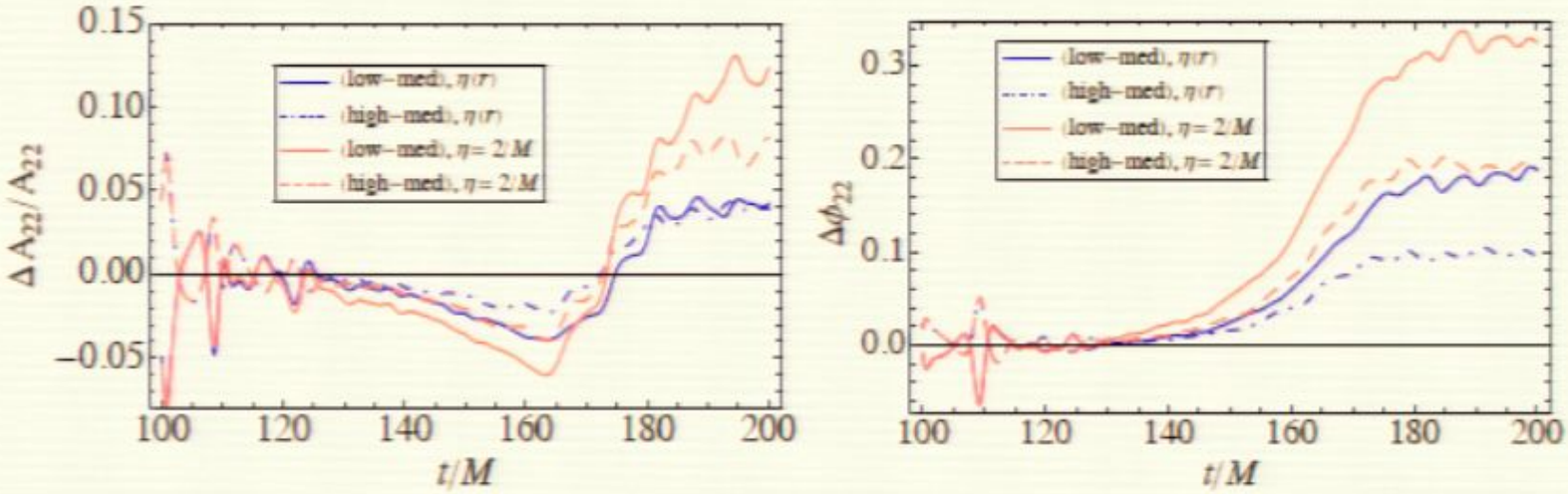
$\tilde{\Gamma}$–driver condition

$$\partial_0^2 \beta^i = \frac{3}{4}\partial_0 \tilde{\Gamma}^i - \eta\, \partial_0 \beta^i$$

$$\eta(\vec{r}) = A + \frac{C_1}{1 + w_1 (\hat{r}_1^2)^n} + \frac{C_2}{1 + w_2 (\hat{r}_2^2)^n}$$

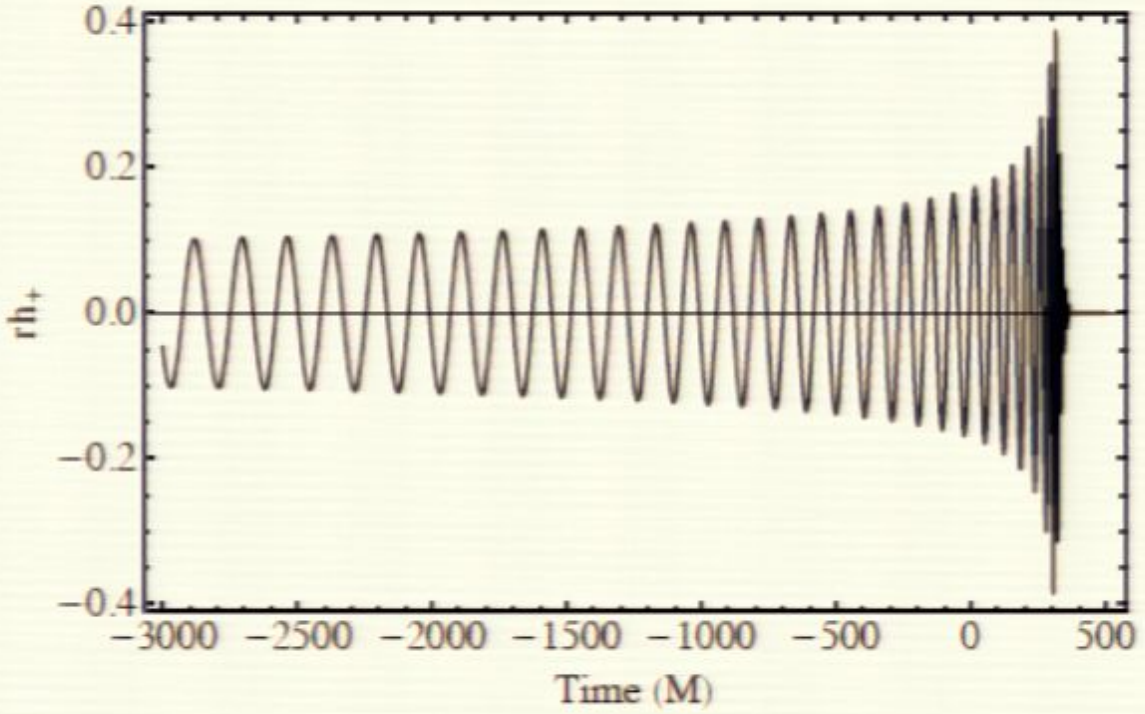


[D. Müller, J. Grigsby, B. Brügmann, arXiv:1003.4681]

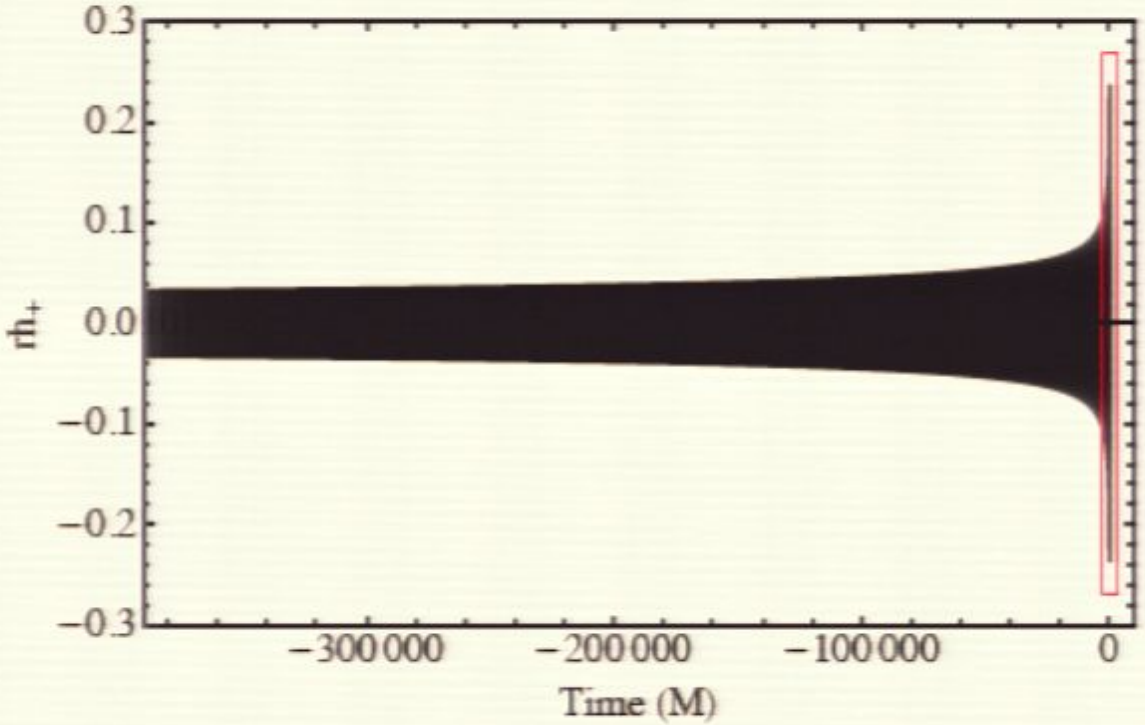
Part II

How long do numerical waveforms need to be?

“long” numerical waveform



hybrid PN+NR waveform



PN expansion of phase evolution

$$x(t) = \omega(t)^{2/3}$$

$$\dot{x}(t) = A\,x(t)^5\left(1 + a_{1\mathrm{PN}}\,x(t) + a_{1.5\mathrm{PN}}\,x(t)^{1.5} + a_{2\mathrm{PN}}\,x(t)^2 + \ldots\right)$$

Numerical errors are negligible

Ambiguities in the hybridization process are negligible

PN errors dominate

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Do you want 10 waveforms, or 1000?

Do you want them in 6 months, or 6 years?

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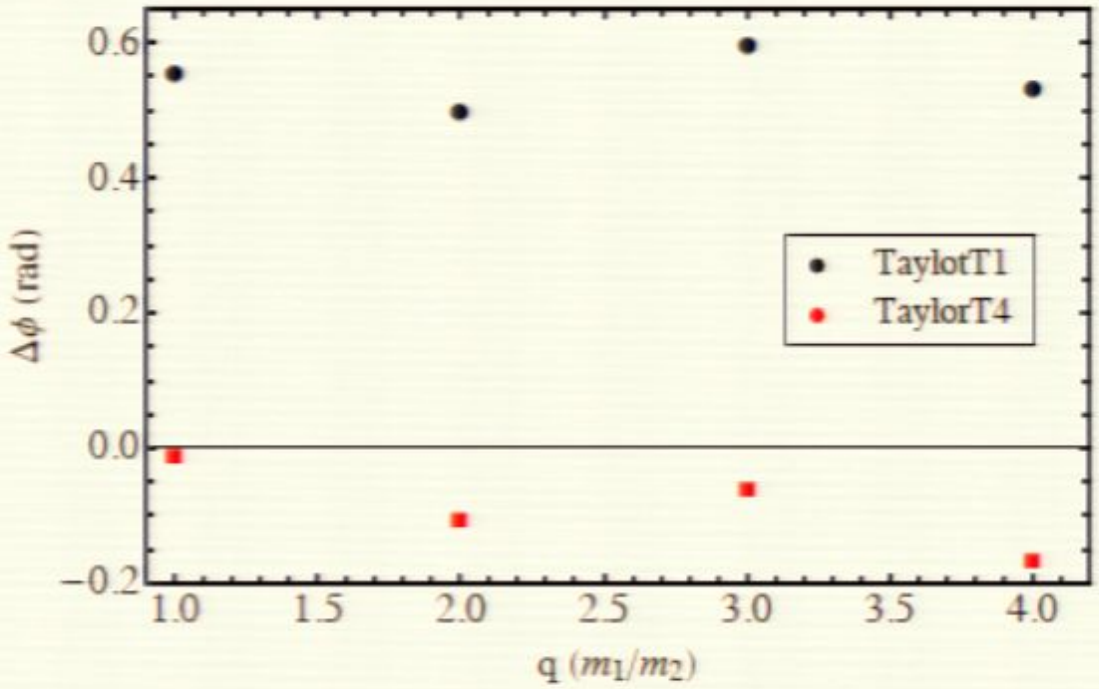
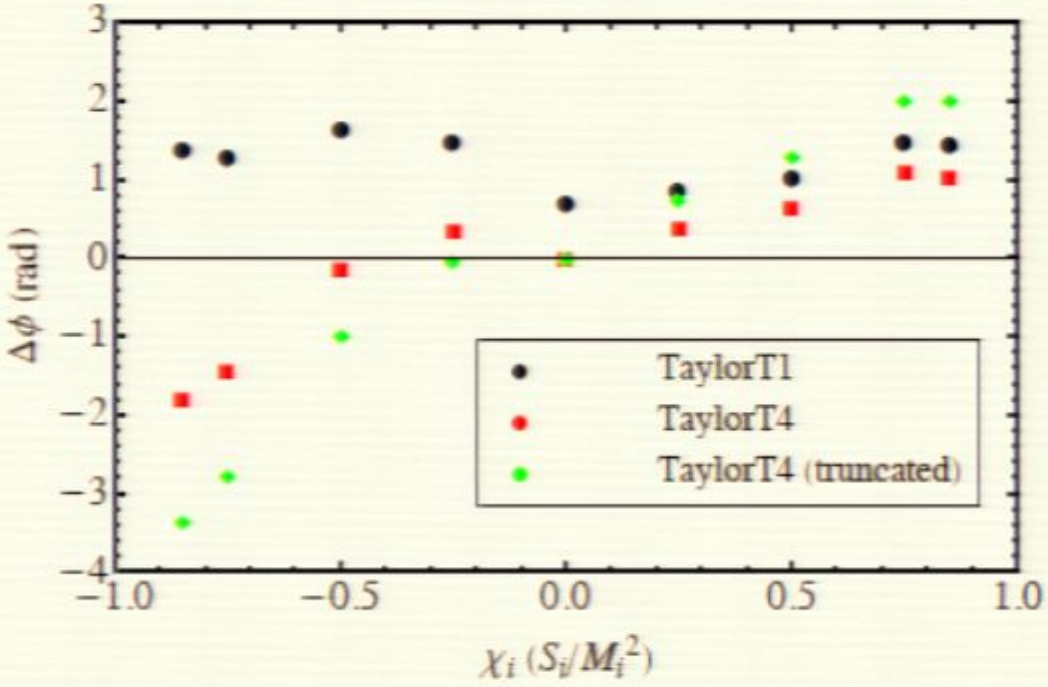
accumulated PN-NR phase disagreement



Unequal-mass, nonspinning cases

accumulated PN-NR phase disagreement



Equal-mass, spinning cases

Want to know accuracy of hybrid waveforms!

Requirement for detection:

Mismatch of $\mathcal{M} < 0.03$ means we lose $< 10\%$ of signals

If mismatch error of hybrid is $> 3\%$, it's no good!

Determining waveform length

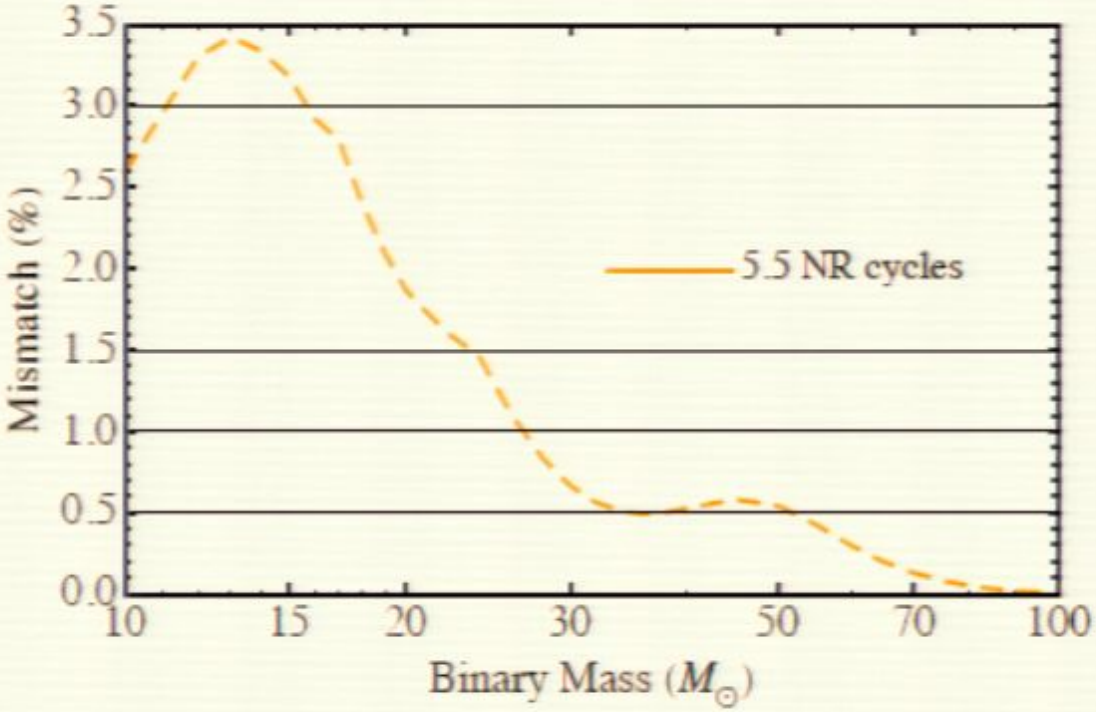
Treat TaylorT4 + PN hybrid as the "true" waveform

Consider it as a very long numerical waveform, NR_L

Compare T1+NR_L hybrids with NR_L

Vary the number of "numerical" NR_L cycles

Equal-mass, nonspinning



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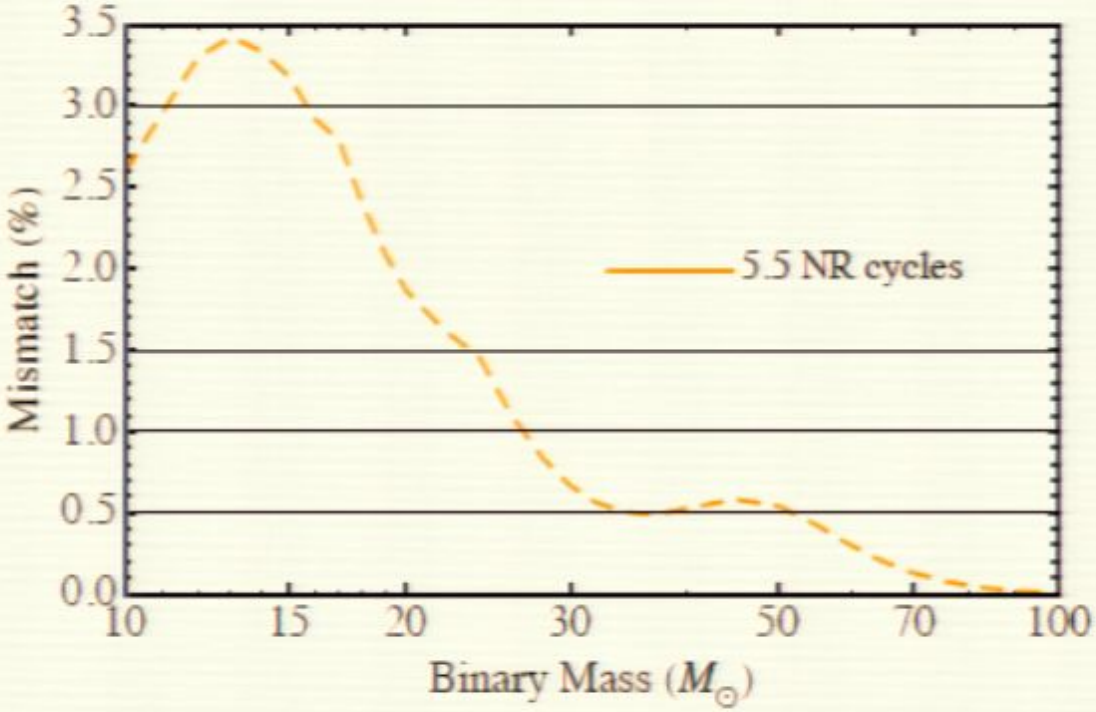

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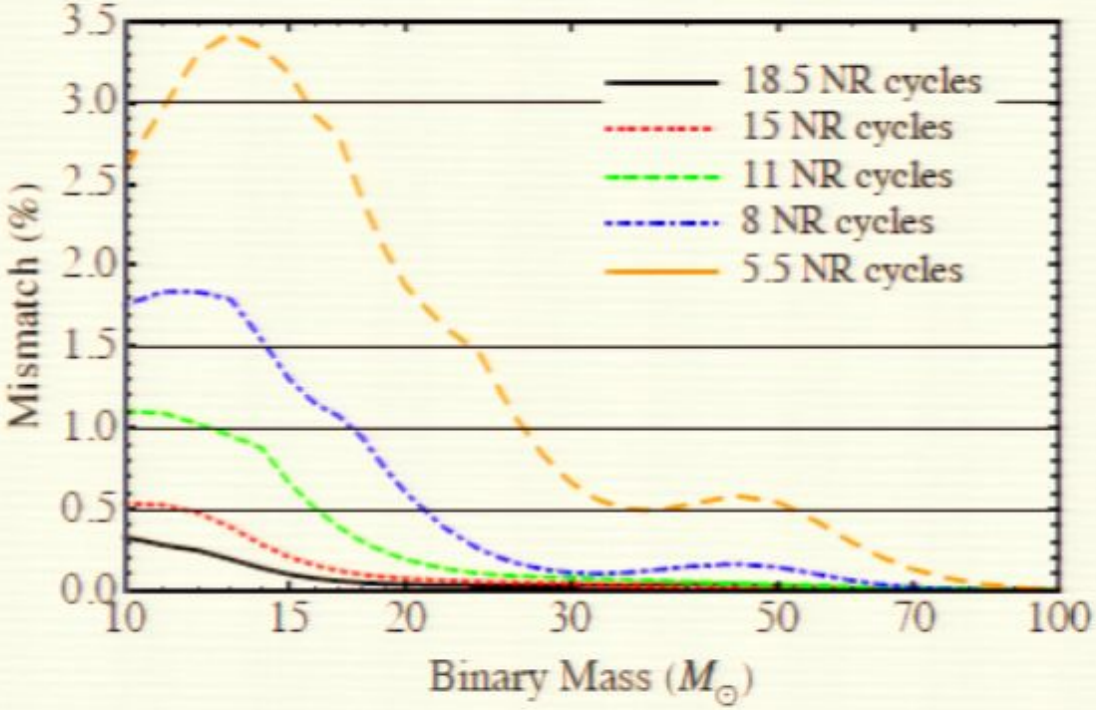
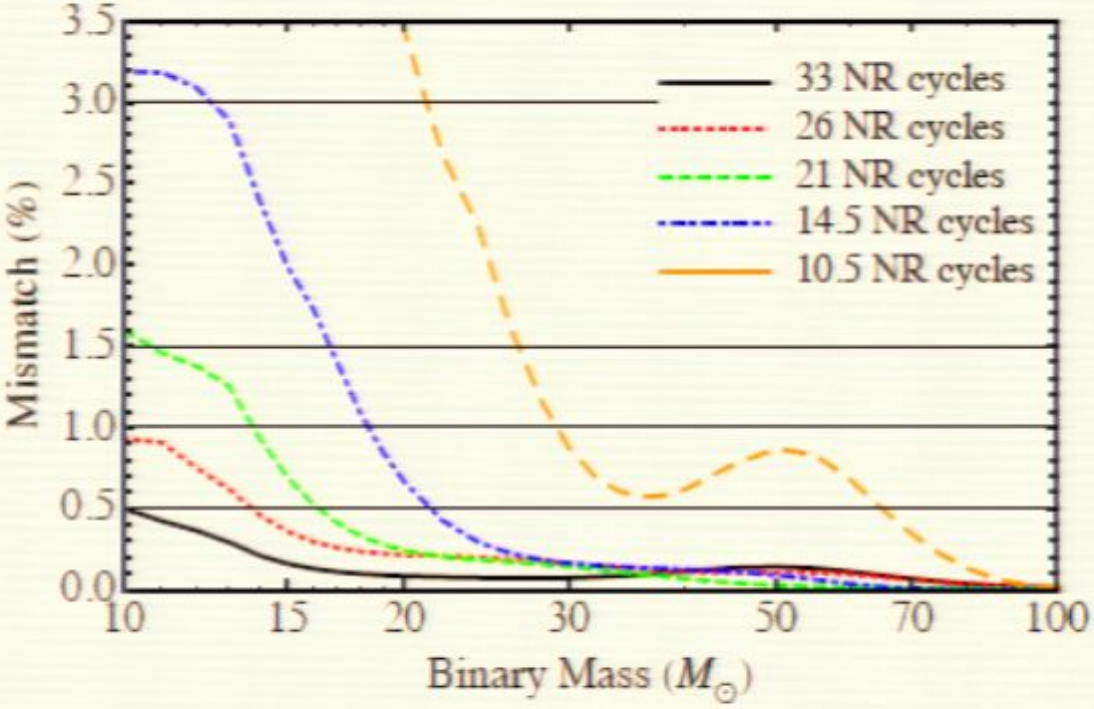


8 cycles ($<$ 4 orbits) are enough!

Unequal-mass, $q = 4$



21 cycles (9.5 orbits) are enough

Spinning binaries

Need a better-behaving approximant

Modify T4:
Add 3PN and 3.5PN terms

Optimize 3/3.5PN
coefficients
with respect to
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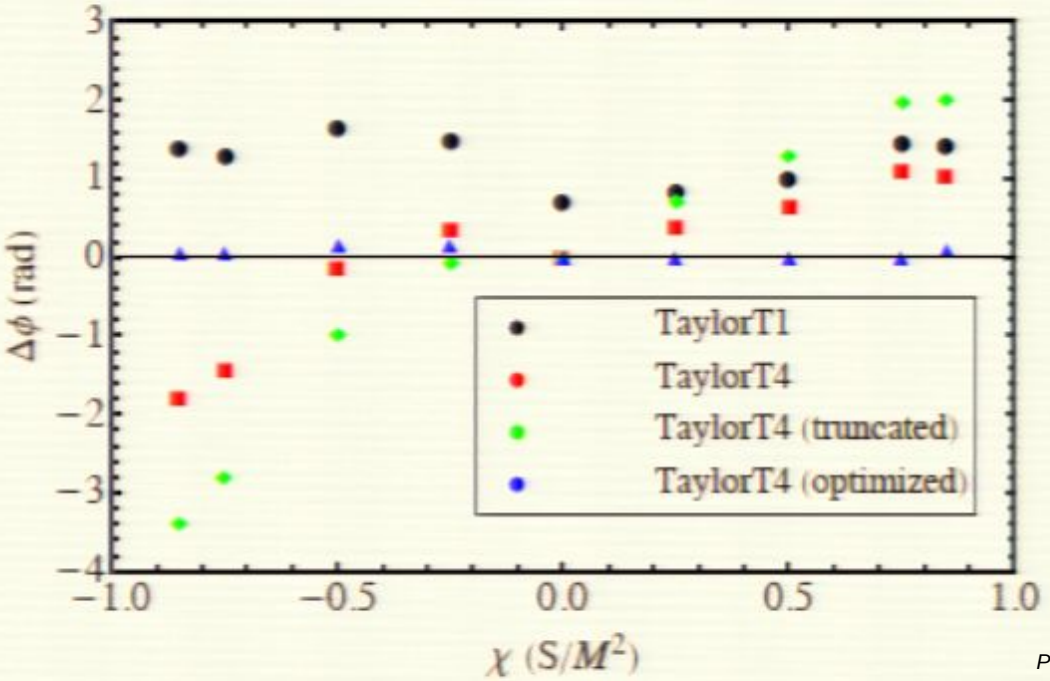
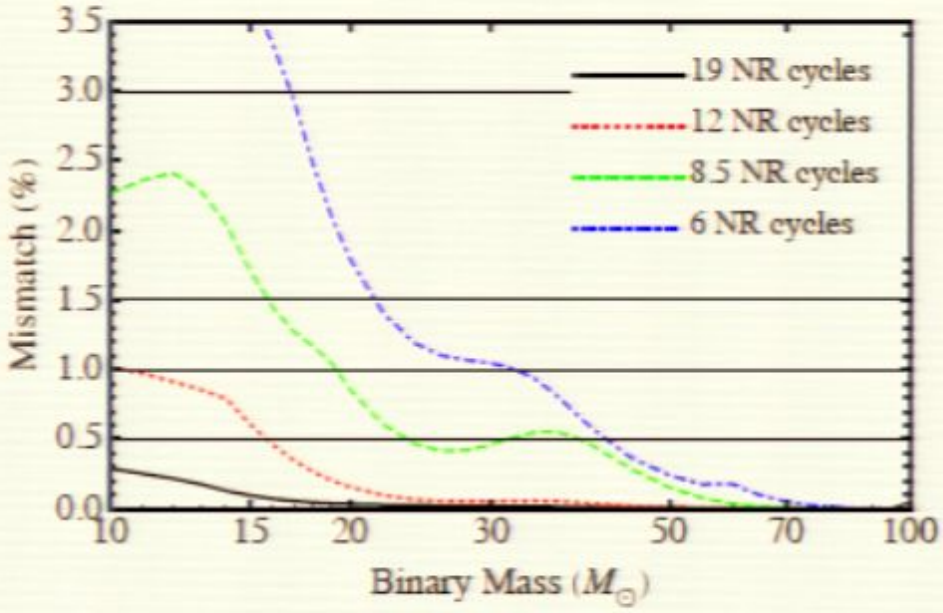
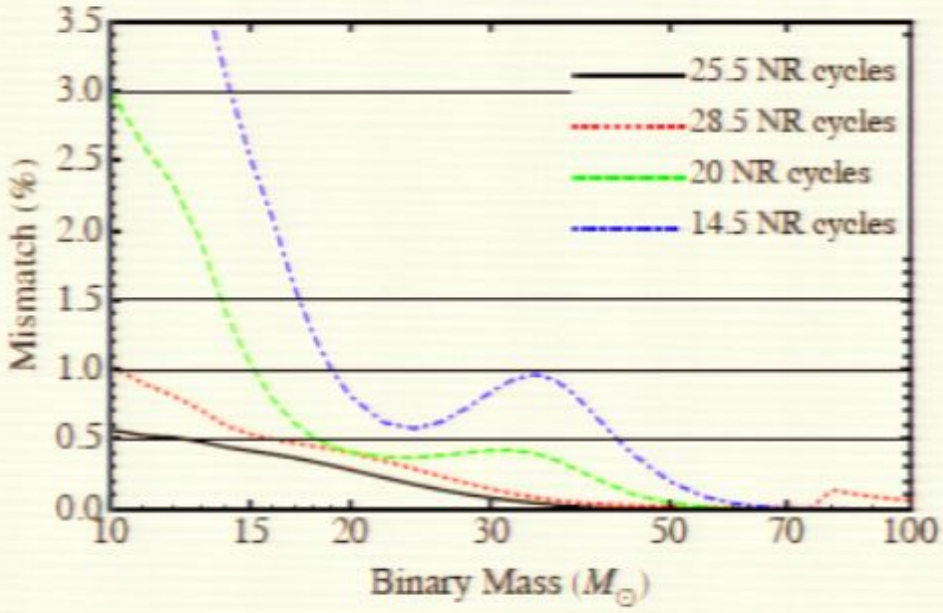




$\chi_i = -0.5$: **10 cycles (5 orbits)**



$\chi_i = +0.5$: **25 cycles (12 orbits)**

Conclusion

hybrid waveform accuracy determined by PN errors

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Current results suggest:

$q \approx 1$, low spins: 5 orbits are enough

Moderate mass ratios, higher spins: 10 orbits are enough

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Large mass ratios? Large spins? Precessing spins?

Is this analysis too conservative? Too optimistic?